Visual Behavior and Preference Decision-Making in Response to Faces in High-Functioning Autism

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ABSTRACT

How do we come to the decision that we like a face? This thesis investigates this important aspect of social processing and communication by examining preference decisions for faces and the role that visual behavior plays in the process. I present a series of studies designed to investigate face preference formation and gaze patterns using eye-tracking and self-reported preference ratings. I tested healthy control subjects and two clinical populations known to have deficits in social processing: people with autism and patients with amygdala lesions. In studies one and two, I explore whether known social cognition deficits in people with autism and amygdala lesions also impair subjective decision-making regarding the attractiveness of faces. In study three, I investigate the flexibility of rule-based visual strategies used by these populations during face perception. Additionally, I present a custom algorithm developed to process raw eyetracking data, which was used to analyze all eyetracking data in this thesis.

People with autism and patients with amygdala lesions are known to have general deficits in social processing, including difficulty orienting toward and evaluating faces. Nevertheless, I find that their behavior is markedly similar in many areas where we would expect them to have abnormalities or deficiencies. Their preference decisions when judging facial attractiveness were highly correlated with those made by controls, and both groups showed the same biases for familiar faces over novel faces. In addition, people with autism exhibit the same visual sampling behavior linking preference and attentional orienting, but reach their decisions faster than controls and also appear insensitive to the difficulty of the choice. Finally, gaze to the eye region appears normal in the absence of an explicit decision-making task, but only when analyzed in a similar manner as previous studies. However, when face sub-regions were analyzed in greater detail, people with autism demonstrate abnormalities in face gaze patterns, failing to emphasize the most information-rich regions of the face. Furthermore, people with autism demonstrate impairments in their ability to update those gaze patterns to accommodate different viewing restrictions. Taken together, these findings support the idea that the normal formation of face preferences can be preserved in the presence of general social processing impairments. Patterns in the eyetracking and behavioral data indicate that this is made possible, in part, by compensatory atypical processing and visual strategies.

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INTRODUCTION

1.1 General Overview

Human faces and facial expressions are central to social communication. Our ability to accurately evaluate and make decisions about faces is a vital component of social functioning, enabling us to perceive emotions, decode others' intentions, and form social bonds. The visual and cognitive mechanisms involved in face processing are in large part subconscious and automatic, yet they wield an enormous influence on our judgments about faces and emotional expressions and, ultimately, on our social behavior. While most of the extant research on face processing focuses on visual behavior during objective decision-making tasks, such as face discrimination or emotion recognition, few studies investigate the influence of visual behavior on *subjective* decision-making with regard to faces. Much of our day-to-day social behavior is not based on objective and explicit processing, but is instead based on cues that are processed subjectively and automatically. As such, an important but overlooked aspect of social decision-making processes is the question of *how* we evaluate faces and ultimately determine if we like them. While subjective judgments and the behavior that accompanies them can be more difficult to operationalize than objective judgments with empirically correct answers, subjective decision-making can be at least partially quantified through scientific methods such as eyetracking and behavioral measures in an effort to better understand how we subjectively evaluate faces.

Autism is a pervasive developmental disorder in which social perception, and the processing of faces in particular, is disrupted. Research has shown that individuals with autism spectrum disorders (ASD) have deficits in evaluating and making social judgments about faces, and demonstrate atypical gaze behavior toward social stimuli including inattention to faces and direct gaze aversion. By examining the visual behavior of individuals with autism in social processing tasks, we can investigate the role of automatic responses to faces, as well as learn about the essential components involved in the formation of preference judgments for faces.

The aim of this thesis is to investigate the automatic and subconscious components of visual behavior that influence how we examine faces, and how these components of visual behavior can affect the way in which we subjectively evaluate faces. Specifically, how do we come to the decision that we like a face or not? One way to explore this question is to compare clinical populations that demonstrate impairments in social functioning, such as individuals with autism or amygdala lesions, to healthy controls (also referred to as neurotypicals) during social processing tasks. We know that subjects with autism show deficits in orienting towards and processing socially-salient stimuli, with a particular deficit in the evaluation of faces, which may in turn be linked to amygdala dysfunction.

The current research involves a series of studies investigating specific elements of visual behavior and preference formation for faces across three populations: healthy controls, people with autism, and amygdala lesion patients. In the first study, I explore visual behavior during preference decision-making for both social stimuli and non-social stimuli. When comparing healthy controls to autism and amygdala lesion patients, I examine whether the processes that are disturbed in making objective judgments about faces also affect subjective decision-making about faces. In the second study, I investigate one well-known aspect of face preference formation reported in healthy populations—a preference bias for familiar faces over those that are novel—in order to examine whether social processing deficits affect preference formation for familiar faces. In the last study, I explore the use and flexibility of atypical face viewing strategies that can partly compensate for social processing deficits.

In the remainder of this Introduction, I will review the literature that is necessary for understanding the studies and results in this thesis. First, I will present an overview of social attention and face processing in neurotypicals, and discuss what is known regarding face processing deficits in ASD. Second, I will review neuroanatomical abnormalities that are linked to social processing deficits in ASD, and the possible association with amygdala dysfunction. Lastly, I will present an outline of my dissertation and high-level findings from each of the studies.

1.2 Background and Context

1.2.1 Social attention and face perception in neurotypicals

Faces and facial expressions are a meaningful source of social and affective information, and studies show that faces and facial expressions have a unique ability to attract and hold our attention. There is extensive research available on the social attention and face perception of neurotypicals, which is briefly reviewed in this section. One powerful methodology used by researchers to study face processing is eye-tracking, whereby a person's eye movements are recorded to analyze where a subject is looking and directing their attention in relation to a visual stimulus. Eye movement patterns are widely regarded as an indicator of visual and attentional processes involved in performing a task. Tracking subjects' eye movements during viewing of social stimuli, such as faces, therefore provides a useful measure of where people are directing their attention during social and face processing tasks.

In 1967, in one of the earlier eyetracking studies examining the social saliency of faces, Alfred Yarbus showed participants the painting *Unexpected Visitors* (Repin, 1884) and examined how the viewers' gaze moved across the picture (Yarbus, 1967). Yarbus recorded the participants' eye movements using a homemade eyetracking device affixed directly to the eye with suction. He found that the faces of people depicted in the painting attracted the most visual attention compared to the rest of the elements in the scene. That is, the viewers' eyes would often pause, or fixate, upon faces rather than other parts of the picture. Since Yarbus's research, the social saliency of faces for neurotypicals has been demonstrated in many other studies (Palermo & Rhodes, 2007; Posamentier, 2003; Theeuwes & Van der Stigchel, 2006; Vuilleumier, 2000), particularly through experiments using increasingly more modern techniques such as eyetracking and neuroimaging. Such experiments have demonstrated the important role that social attention plays in human interaction.

As social animals, humans have a heightened attentional bias for biologically relevant stimuli, such as human figures and faces. For example, neurotypicals show preferential attention for exploring social stimuli, including depictions of people and social interactions (Birmingham, Bischof, & Kingstone, 2008; Tipper, Handy, Giesbrecht, & Kingstone, 2008). Interestingly,

the attentional bias toward human figures is evident even in the first fixation made after an image is presented (Fletcher-Watson, Findlay, Leekam, & Benson, 2008), indicating that the presence of a person in an image can be processed rapidly and subconsciously prior to the first fixation. This finding points to face-sensitive perceptual mechanisms that function pre-attentively or within the bounds of attention, but at a remarkably swift speed, meaning a great deal of social processing occurs subconsciously and automatically. This is particularly intriguing with respect to the amygdala, a key neural structure involved in directing social attention. The relationship between social processing and the amygdala will be discussed later in this chapter.

Several studies have examined the visual preference choices made by neurotypical individuals. For example, Shimojo and colleagues (2003) have shown that preference and gaze interact in a positive feedback loop to produce a phenomenon known as the "gaze cascade" effect (S. Shimojo, Simion, Shimojo, & Scheier, 2003). The effect is observed when choosing between social stimuli, as well as when choosing between non-social stimuli. When observers are shown pairs of images and instructed to choose which of the two they prefer, their gaze is equally likely to be on either picture. However, in the few seconds before a decision is made, a gaze bias builds toward the stimulus that is eventually chosen, increasing until the person makes a decision. The bias occurs outside of the person's awareness, and is present before the person is conscious of his or her final preference. It is hypothesized that this increasing gaze bias reflects a positive feedback loop between two behavioral factors that are critical for forming the eventual preference: people tend to look more at an image they prefer, and people tend to prefer images that they have seen more.

With regard to the latter factor, it is known that our preferences are strongly influenced by our previous experiences with certain stimuli. Repeated visual exposure to a stimulus is known to increase our preference for it up to a certain point (Zajonc, 1968), a phenomenon termed the "mere exposure" effect since even subliminal exposure is sufficient for increasing preference for geometric stimuli. More recent studies, however, have suggested that the familiarity preference is specific to certain stimulus categories but not others (Liao, Yeh, & Shimojo, 2011; Park, Shimojo, & Shimojo, 2010). When subjects are presented with pairs of faces, and

instructed to judge for preference, people prefer the faces that are familiar. But the opposite occurs with nature scenes: when presented with pairs of nature scene images, people prefer the images that are novel. In other words, healthy controls demonstrate a familiarity bias for faces but a novelty bias for nature scenes. The authors suggest the familiarity preference for faces, which will be discussed further in Chapter 3.4, might be driven by the preferential attention that is afforded to faces over other non-social stimuli.

There is considerable evidence to indicate that faces enjoy preferential attentional capture in normally developing individuals (Vuilleumier, 2000). The reflexive attraction to faces is so robust in neurotypicals that it occurs even when it would be beneficial to inhibit it (Bindemann, Burton, Hooge, Jenkins, & De Haan, 2005; Gilchrist & Proske, 2006; Theeuwes & Van der Stigchel, 2006). That is, by showing a face in the field of view, individuals cannot help but employ attentional resources to process it, even when doing so subsequently distracts from the goals of a competing task. In one study, Langton and colleagues (2008) reported that participants were slower to find a non-social image when a face was also present on-screen compared to when a face was absent (Langton, Law, Burton, & Schweinberger, 2008). In other words, a face that had no relevance to the visual target for which participants were searching slowed their ability to search for a different target because the face automatically engaged viewers' attention. These findings demonstrate that faces are not only spontaneously detected and attended to, but also indicate that it is harder to disengage from a face compared to a non-face object once one's attention has been captured by it.

Healthy individuals have also been shown to be more attuned to changes involving faces than those involving other objects (Beck, Rees, Frith, & Lavie, 2001). A study by Ro, Russell, and Lavie (2001) found that changes involving faces—such as a face changing to a different face—are detected faster and more accurately than changes in other object categories, such as pictures of food or musical instruments (Ro, Russell, & Lavie, 2001). Interestingly, reaction times for detecting changes to a face increased the *less* complex the scene was. The authors interpreted this effect to indicate that the more competition there is for visual attention in a scene, the more privilege faces are afforded. That is, faces have even greater saliency when competing against

other non-face stimuli for attention. Thus, in typically developing people, faces enjoy privileged status, engaging and holding attention quicker and longer than non-social objects.

The preference in attention toward faces and face-like configurations over other objects in the environment seems to be innate in many respects. For example, spontaneous orienting to faces is a behavior present from birth: newborn infants (participants in the study were an average of nine minutes in age) show heightened interest in faces, turning their heads more frequently to gaze at images whose internal elements are configured to resemble actual faces than at images with the same internal elements scrambled, or a blank image (Goren, Sarty, & Wu, 1975). Infants also direct their first fixations to face-like patterns more often than would be observed by chance, even when other stimuli are competing for visual attention (Gliga, Elsabbagh, Andravizou, & Johnson, 2009). These results show that the basic neural architecture for attending to and evaluating faces for social information is present in some form even at an early age.

Indeed, the brain is primed to attend to faces even in their most basic configuration and the presence of specific rudimentary visual cues automatically elicits face processing in neurotypicals. One such cue is the arrangement of facial elements in an upright, T-shaped configuration. In other words, neurotypicals rely more on the arrangement of facial features rather than on individual facial features while performing face processing tasks (Calder & Young, 2005). For example, inverted faces are harder to recognize than upright ones, (Kanwisher, Tong, & Nakayama, 1998; Tanaka & Farah, 1993)**,** and faces that are presented whole are detected more quickly than faces whose elements are scrambled (Hershler & Hochstein, 2005), indicating that facial features alone do not receive preferential attention, but that the appropriate configuration is preferentially processed and detected. These findings highlight a key component of face perception in neurotypicals, which is configural processing. The tendency to attend to an upright, T-shaped configuration as a potential social stimulus is so entrenched in neurotypicals that the presence of actual facial elements is not necessary to capture visual attention—schematic faces (for example, a grey oval overlaid with two black circles positioned above a third black circle to resemble two eyes and a mouth) also elicit the same effect: individuals are quicker to direct attention to an upright schematic face than an

inverted one (Tomalski, Csibra, & Johnson, 2009). Taken together, these findings demonstrate that the brain is primed to recognize and evaluate faces in even their most basic configurations. One reason behind these findings may be that the face holds special significance in its ability to communicate social information, which will be discussed next.

1.2.2 Social processing of faces

Faces communicate a wealth of information regarding people's emotions, attention, and future intentions, and neurotypical individuals quickly and effortlessly evaluate faces to process this social information. One vital component underlying neurotypicals' ability to process facial information is the spontaneous tendency to prioritize gaze to specific facial features over other parts of the face. When viewing faces, individuals' fixations are largely clustered around the key facial features that communicate the greatest amount of emotional and social information: first the eyes, followed by the mouth and nose (Luria & Strauss, 1978; Stephen, Wellens, Goldberg, & Dell'Osso, 1978; Walker-Smith, Gale, & Findlay, 1977). At a glance, these regions are evaluated and processed to form an impression of another person's mental state. Anger is quickly recognized by the downward turn of the inner eyebrows (Jones, 1974; Yarbus, 1967), combined with pursed or scowling lips (Kohler et al., 2004), disgust is perceived from a wrinkled nose and raised upper lip (Rozin, Lowery, & Ebert, 1994; McIntosh, 2006), and fear is recognized by the widening of eyes and increased amount of visible sclera (Whalen et al., 2004), along with a stretched mouth (Kohler et al., 2004). In addition to a smile, genuine happiness is recognized by the contraction of muscles surrounding the eyes, known as orbicularis oculi (Williams, Senior, David, Loughland, & Gordon, 2001).

The eyes in particular are central to social communication and they convey an extensive amount of information regarding stable physical traits, such as age (Nguyen, Isaacowitz, & Rubin, 2009) and gender (Brown & Perrett, 1993), as well as dynamic, transient states such as intention and emotion (Kleinke, 1986). Eye gaze direction, for instance, is a highly salient cue for establishing social intention and interaction, signaling either initiation or avoidance of social contact (Argyle et al., 1973; Argyle & Cook, 1976). Direct eye gaze indicates a person's attention is directed at the perceiver and that the person intends to engage with the perceiver, while averted gaze indicates a person's attention is directed elsewhere (for a review of levels of

social gaze and their meaning, see Emery, 2000). Emotions are another dynamic cue that can be communicated just by the eye region. Complex emotional states—such as admiration, arrogance, boredom, and guilt—can be identified just as well from the eyes as from the whole face (Baron-Cohen, Wheelwright, & Jolliffe, 1997). Thus, the eyes are a highly salient cue for social communication and interaction. For this reason, in social processing tasks and in tasks investigating where neurotypicals naturally orient their gaze, the eyes are the elements of the face that are fixated upon most frequently and for longer durations of time than other regions of the face (Itier, Villate, & Ryan, 2007; Stephen et al., 1978). Like the general salience of the face, the salience of the eyes is also present in early infancy. Infants direct more of their attention to faces with open eyes compared to closed eyes (Batki, Baron-Cohen, Wheelwright, Connellan, & Ahluwalia, 2000), as well as to faces showing direct gaze compared to averted gaze (Farroni, Csibra, Simion, & Johnson, 2002).

The visual cues contained in faces, such as emotional expressions and direction of eye gaze, also guide our attention to facilitate further processing. For example, behavioral studies have shown that detection and discrimination of faces is enhanced when the faces depict emotional expressions. Faces expressing happiness, surprise, or disgust are more likely to attract viewers' first fixations and are also detected faster than neutral facial expressions (Calvo & Nummenmaa, 2008; Ro et al., 2001). Calvo and Esteves (2005) reported that emotional expressions of anger, happiness, and sadness could be detected and discriminated in as little as 25 milliseconds, whether faces were presented within or outside of the foveal field of view (Calvo & Esteves, 2005), indicating that facial cues can modulate attentional orienting. Studies have also shown that emotional expressions can be perceived pre-attentively—meaning outside of conscious perception—and then guide our active attention to the face's location (Eastwood, Smilek, & Merikle, 2001). In addition to emotional expression, a similar facilitative effect is observed with direct eye contact. Neurotypical individuals are quicker to detect faces showing direct gaze compared to averted gaze (Senju, Yaguchi, Tojo, & Hasegawa, 2003). Furthermore, studies have shown that direct eye contact facilitates recognition of gender (Macrae, Hood, Milne, Rowe, & Mason, 2002) and identity (Hood, Macrae, Cole-Davies, & Dias, 2003). These studies demonstrate that the processing of certain basic social cues takes

place automatically and subconsciously, and that these cues can modulate further, and often more complex, social processing by directing visual attention.

In addition to rapid processing of facial features for emotion and intention, people also form impressions of social traits based purely on facial features, and they do so in a remarkably brief amount of time. With a quick glance at a person's face, often as little as 50 milliseconds, people are able to make a variety of social judgments regarding others, evaluating intelligence, attractiveness, aggressiveness, and competence (Bar, Neta, & Linz, 2006; Olson & Marshuetz, 2005; Rule, Ambady, & Adams, 2009). The characteristics perceived in the initial stages of seeing a person's face prove to be influential in determining the social traits ascribed to that individual. For example, one study showed that neurotypicals make inferences about attractiveness, trustworthiness, competence, and aggressiveness when perceiving a face in as little as 100 milliseconds after exposure (Willis & Todorov, 2006). Additionally, judgments that were made in 100 milliseconds strongly correlated with judgments that were made in the absence of a time restriction, indicating that a time window of 100 milliseconds is sufficient to automatically invoke a variety of complex social inferences.

The automatic and subjective inferences people make for characteristics such as trustworthiness and attractiveness affect social judgments and behavior in neurotypicals. For example, research has shown that these social inferences affect election outcomes (Ballew & Todorov, 2007), professional success (Dipboye, Arvey, & Terpstra, 1977; Shahani-Denning, 2003), consumption behavior (Winkielman, 2005), and even sentencing leniency in the judicial system (Stewart, 1980). Furthermore, people attribute different qualities based on perceptions of attractiveness: more attractive people elicit more positive impressions of competence (Eagly, Ashmore, & Makhijani, 1991) and even more attractive babies are viewed as being more responsive and intelligent than their less attractive peers (Langlois et al., 2000).

The social and affective information communicated by faces, therefore, is largely evaluated subconsciously and automatically, and based on this information, neurotypicals make inferences that affect social behavior and real-world outcomes. While the automatic processing and evaluation of faces is a crucial domain of social processing in neurotypicals, it has been

shown to be compromised in individuals with social disorders such as autism spectrum disorder (ASD) (Dawson et al., 2004; Katarzyna, Fred, & Ami, 2010; Remington et al., 2012). Studying face processing in people with ASD can provide insight into both the neurological processes underlying face perception and the underlying symptomology in ASD and other disorders in which social processing is impaired.

1.2.3 Social saliency in autism

Autism is a pervasive developmental disorder with core diagnostic criteria that include restricted and repetitive behaviors and interests, and deficits in social communication and interaction (Diagnostic Statistical Manual of Mental Disorders - 5th ed.; American Psychiatric Association, 2013). Individuals with autism have impairments across a variety of domains, including deficits in orienting towards social cues such as eye gaze (Dawson et al., 2004; Elsabbagh et al., 2012; Jones, Carr, & Klin, 2008), and difficulty processing social and emotional information (Ashwin, Chapman, Colle, & Baron-Cohen, 2006; Forgeot d'Arc et al., 2014; Smith, Montagne, Perrett, Gill, & Gallagher, 2010).

Few studies exist on face preference formation in ASD. Moreover, the two studies that have directly investigated face preference have drawn mixed conclusions. Da Fonseca, Santos, Rosset, and Dereulle (2007) reported people with ASD have similar attractiveness preferences as neurotypicals, and moreover, they demonstrate a similar tendency to attribute more positive qualities to faces perceived as more attractive (Da Fonseca, Santos, Rosset, & Deruelle, 2011). While a study by White, Hill, Winston and Frith (2005) also reported that attractiveness judgments in ASD did not differ from the judgments made by neurotypicals, in contrast to da Fonseca and colleagues (2007), they found that people with ASD were impaired in the ability to judge attractiveness of faces if they were the same sex as the participant (White, Hill, Winston, & Frith, 2006).

Studies examining social perception in ASD have found reduced saliency of social stimuli relative to non-social stimuli in the disorder (Dawson, Webb, & McPartland, 2005). In addition to a decreased attentional bias in response to faces, when people with autism do look at faces, they demonstrate atypical fixation behavior towards them (Fletcher-Watson, Leekam, Benson,

Frank, & Findlay, 2009), fixating more on the mouth than neurotypicals (Klin, Jones, Schultz, Volkmar, & Cohen, 2002; Spezio, Adolphs, Hurley, & Piven, 2007), as well as showing reduced eye contact (Jones & Klin, 2013; Katarzyna et al., 2010).

Although the exact abnormalities characterizing atypical eye gaze are still a matter of debate, a number of studies report differences in the eye gaze patterns of people with ASD, indicating they either avoid or simply lack interest in the eye region. Eyetracking studies have revealed that individuals with autism look less at the eyes of an emotionally expressive face than do neurotypicals (Corden, Chilvers, & Skuse, 2008; Dalton et al., 2005; Klin et al., 2002; Pelphrey et al., 2002; Riby & Hancock, 2008). Moreover, extant research has also indicated that people with autism fail to use information from the eyes to identify complex mental states such as shame or envy (Jolliffe & Baron-Cohen, 1997), and that they rely more on the mouth than the eyes for social information (Neumann, Spezio, Piven, & Adolphs, 2006).

Atypical gaze behavior is also linked to abnormalities in individuals' ability to evaluate social information expressed through faces. For example, some studies have reported that high- and low-functioning individuals with autism present impaired recognition of facial expressions compared to controls (Hobson, 1986; Tantam, Monaghan, Nicholson, & Stirling, 1989). While these impairments might be restricted to the recognition of specific emotions such as fear, anger, and sadness (Ashwin et al., 2006; Bal et al., 2009; Wallace, Coleman, & Bailey, 2008), there is also evidence to suggest a more global impairment in emotion recognition (Rutherford & McIntosh, 2006; Tardif, Lainé, Rodriguez, & Gepner, 2007).

Social deficits in autism might also differ based on levels of intellectual disability. In people with high-functioning autism (which generally refers to diagnosed individuals who can communicate, carry out basic tasks, and have less intellectual impairment), there is evidence to suggest social impairments are restricted to higher-order social judgments rather than basic aspects of social perception. While social attributions that require higher-order judgments, mentalizing, or theory-of-mind inferences are more consistently impaired in individuals with high-functioning autism, some studies report that lower-level social processes are not impaired, such that basic skills, like emotion perception, remain intact (Adolphs, Sears, & Piven, 2001;

Jolliffe & Baron-Cohen, 1997). The pathways associated with complex aspects of processing facial and emotional expressions—such as the retrieval of social knowledge that allows us to recognize a familiar face, conceptual information about others' mental and emotional states, or the generation of complex emotional responses in the viewer—might be separate from or compensated for by other pathways that allow for basic social processing, such as the recognition of simple emotions or face preference judgments. Therefore, high-functioning autistic individuals' ability to process more basic social information might not be affected by the face processing deficits commonly observed in autism. Such heterogeneity in symptoms among ASD sub-groups is common and, as discussed below, has led to some difficulty in finding consistent symptomology across the entire ASD population.

1.2.4 Divergent behavioral findings in autism research

Social processing deficits in ASD are poorly understood in relation to diagnostic sub-groups as well as the known heterogeneity in symptomology. To add to this complexity, individuals within the same sub-group can express different subsets of reported symptoms, and differ in the severity of those symptoms. Consequently, the large body of extant studies on face processing in ASD has generated somewhat mixed results. Although researchers initially expected that people with ASD would present significant, overt deficits in the processing of faces and other social stimuli, it is now understood that social perception in autism is heterogeneous, resulting in widely varying reports of social impairment. Such highly conflicting results led to the conclusion in a recent review by Harms et al. (2010) that social perception in ASD depends on numerous factors, including the known heterogeneity in ASD in terms of symptom variability and severity, participant demographics (e.g., age, gender, etc.), experimental differences in stimuli and task demands, and the use of compensatory strategies in high-functioning individuals with ASD (Harms, Martin, & Wallace, 2010).

Various studies have shown that the differences between high-functioning individuals with ASD and neurotypicals often appear to be subtle due to the use of compensatory, top-down strategies in autism that mask social deficits (Rutherford & McIntosh, 2006; Teunisse & de Gelder, 2001; Wong, Fung, Chua, & McAlonan, 2008). For example, Grossman and colleagues reported that when children with ASD were shown pictures of basic emotional

expressions with matching labels, there was no impairment in recognizing emotions (Grossman, Klin, Carter, & Volkmar, 2000). However, when faces were presented with mismatched labels, children with ASD had difficulty recognizing the emotions, indicating that the subjects had likely relied on the labels—perhaps even subconsciously—to facilitate emotion recognition.

Recent research has expanded on the findings related to top-down strategies in autism by exploring the import of shorter response windows for emotion recognition. Clark and colleagues (2008) reported that while individuals with ASD could extract emotional expressions from faces at long presentation durations as well as neurotypicals could, emotion recognition in the autism group was impaired at shorter presentation durations (Clark, Winkielman, & McIntosh, 2008). This suggests that, with longer presentation times, people with ASD might rely on higher-level cognitive skills to identify emotions, but that rapid, automatic processing is impaired. Taken together, these results indicate that some high-functioning individuals with ASD can compensate for social processing deficits by using top-down, cognitive strategies. However, it is important to note that the studies demonstrate that atypical strategies are limited in flexibility since they cannot be applied in uncommonly encountered situations.

Perceptual (i.e., implicit) strategies for visual processing have also been shown to differ in individuals with ASD, enabling them to outperform controls in certain types of visual perception tasks with non-social stimuli. Evidence in support of this visual processing advantage comes from studies that have shown faster reaction times among individuals with autism in finding embedded figures (Jarrold, Gilchrist, & Bender, 2005; Keehn et al., 2008), as well as enhanced detection of targets in visual search tasks (O'Riordan, Plaisted, Driver, & Baron-Cohen, 2001; O'Riordan & Plaisted, 2001). Explanations for this effect have highlighted the use of implicit processing strategies that emphasize local over configural information by people with ASD (Dawson et al., 2005; Rondan & Deruelle, 2004). More importantly, however, this atypical processing strategy is also believed to underlie the lack of a face inversion effect reported in the literature for ASD (Hobson, Ouston, & Lee, 1988; Langdell, 1978; Tantam et al., 1989), which enables people with ASD to outperform controls in face

perception tasks emphasizing featural processing. These findings indicate that atypical processing confers individuals with ASD an advantage in non-social perception tasks, which also extends to certain face perception tasks.

These differences in face processing may be explained by differences in the default style of processing employed by neurotypicals versus individuals with ASD (Krysko & Rutherford, 2009; Lahaie et al., 2006). While neurotypicals generally engage a configural style of face processing, there is evidence that in some situations, individuals with ASD use a local, more feature-based style as their default (Dawson et al., 2005). Some researchers have argued that in ASD, the face is examined and processed in terms of individual features rather than as a whole, perhaps through use of rule-based strategies. Particularly with respect to emotion processing, people with ASD may learn to recognize social cues by identifying rules that characterize specific facial features in an expression, such as raised corners of the mouth for happiness or a scrunched nose for disgust (Rutherford & McIntosh, 2006). In contrast to this explicit rule-based strategy, neurotypicals rely more often on a holistic, template-based strategy, processing the configuration of the entire set of facial features (Calder & Young, 2005). This is not to say that configural processing is entirely absent in individuals with ASD, as global processing can be engaged by other mechanisms such as attention cueing (Behrmann et al., 2006; Nishimura, Rutherford, & Maurer, 2008), but it does indicate that there is a bias among people with ASD for using local processing strategies as the default. Taken together, the results from these and other face processing tasks point to the likelihood that high-functioning individuals employ as their default a local, feature-based processing to process social information rather than the global, configural-based processing that is used by neurotypicals. This suggests that atypical processing and compensatory strategies can be used to partially counteract deficits in face processing and may help to explain the seemingly divergent results of previous research on ASD individuals.

1.2.5 Abnormal brain structure and connectivity in autism

Altered brain connectivity and neuroanatomical differences are thought to contribute to many of the symptoms observed in individuals with ASD, particularly in the area of social behavior. Current theories regarding brain abnormalities in people with autism emphasize differences in

connectivity between regions, or anomalies in several functionally related structures that can affect a number of cognitive processes and result in the behaviors commonly observed in people with ASD. Early abnormal overgrowth is found in regions underlying functions that are known to be impaired in autism, such as language, social skills, and cognitive skills. Courchesne (2004) reported abnormal overgrowth in both white and grey cerebral matter—particularly dorsolateral and medialfrontal regions—and white cerebellar matter. In addition, atypical growth of the cerebellum is believed to play a role in cognitive and motor dysfunctions that lead to the stereotyped behaviors and reduced exploration commonly reported in children with autism (Courchesne, 2004; Pierce & Courchesne, 2001). Bilateral amygdala enlargement and cerebellar and hippocampal enlargement have also been reported in young children (Courchesne, 2004) and older children (Schumann, 2004) with autism. In particular, the degree of enlargement in the amygdala is closely associated with the severity of impairment in social and communication skills (Munson, Dawson, Abbott, & Faja, 2006), including difficulty recognizing facial expressions (Bachevalier, 2006) and detecting eye gaze (Howard et al., 2000).

Regions that show overgrowth and enlargement in early childhood also show atypically slow growth as well as degeneration and volumetric loss later in life, in some cases. In adolescents and adults with autism, the structures comprising the limbic system—particularly the amygdala, hippocampus, basal ganglia, and prefrontal cortices—are most often implicated in symptoms related to social dysfunction (Uddin, Menon, Young, Ryali, & Chen, 2011). Amygdala dysfunction is known to contribute to disruptions in face perception, which includes decreased eye movements to key features of the face and a lack of orienting toward social and emotional information. However, the exact nature of this abnormality is unclear. For example, Howard et al. (2000) reported impairment in facial expression recognition associated with an *increase* in amygdala volume (Howard et al., 2000), whereas Nacewicz et al. (2006) found smaller than normal amygdalae in people with autism (Nacewicz et al., 2006).

Studies have also revealed structural abnormalities in the Superior Temporal Sulcus (STS) in the form of decreased gray matter (Boddaert et al., 2004), and functional abnormalities in the STS in the form of decreased activity during social judgments (Pelphrey, Shultz, Hudac, &

Vander Wyk, 2011). Disruptions in STS function may drive some of the impairments related to social perception in autism, such as communication deficits involving speech perception and difficulty in understanding the intentions of others from movements of the eyes, mouth, and body.

There is increasing evidence that abnormal functioning of the cerebellum also contributes to motor and cognitive impairments in ASD. The cerebellum is a key brain structure for coordination of cognitive functions involving attention and perception. In children with autism, disruptions in cognitive functions are expressed behaviorally in a restricted range of interests, reduced exploration, and stereotyped behaviors—all three of which have been linked to cerebellar dysfunction (Pierce & Courchesne, 2001). Cerebellar function may similarly be compromised in adults with ASD, as there is evidence of increased cerebellar volumes (Sparks et al., 2002), as well as abnormal neuronal densities in this region in the form of decreased numbers of Purkinje cells (Belmonte et al., 2004).

In addition to the structural differences reported in key brain regions, there is substantial evidence of abnormal functional and structural connectivity linking the various brain regions in adults and adolescents with ASD. The hypothesis of underconnectivity proposes that underfunctioning long-range circuitry in people with autism might cause functional deficits in integrating and synchronizing information between related brain regions (Just, Cherkassky, Keller, & Minshew, 2004), and such deficits would cause a wide range of impairments in language processing, motor coordination and social processing. Structural abnormalities appear as atypically high neuronal connectivity between local regions and low neuronal connectivity between brain regions that lie further apart (Courchesne & Pierce, 2005; Kleinhans et al., 2008), and might also contribute to social impairments observed in autism. Indeed, one study by Barnea-Goraly and colleagues (2004) reported disruptions in white matter tracts between brain regions in subjects with autism (Barnea-Goraly et al., 2004). These regions—including the ventromedial prefrontal cortex, anterior cingulate gyrus, superior temporal sulcus, and amygdala—are strongly implicated in social functioning. Taken together, these studies demonstrate that the brain regions and functional connectivity involved in social

processing are abnormal in individuals with ASD, and that these abnormalities likely contribute to impairments in face processing.

The role of the amygdala in ASD has also been given greater attention in recent years, as the amygdala's function or connections may be compromised in autism (Adolphs, 2002; Baron-Cohen et al., 2000). In neurotypicals, the amygdala is an integral part of the cognitive network for processing social information, and modulates social processing by directing visual attention to salient features of the face (Adolphs, 1999; Brothers, 1990). It is therefore important to have a broader understanding of the role the amygdala plays in social processing, which will be discussed next.

1.2.6 The amygdala: a conductor of social attention

While the recognition and processing of social information in faces draws on multiple brain regions, the amygdala plays a particularly important part. According to Adolphs (2002), the amygdala serves an expansive role in face processing for neurotypicals through a number of mechanisms (Adolphs, 2002). First, the amygdala orients bottom-up attention to socially salient features of the face—such as the eyes or mouth—via feedback mechanisms to visual and attention areas (Amaral & Price, 1984). Modulation of these feedback pathways results in heightened perceptual processing of social stimuli as well as subconscious processing of emotional cues (Amaral, Behniea, & Kelly, 2003; Sander et al., 2005). That is, the amygdala attaches salience to visual input (Adolphs, 1999) and subsequently directs visual attention to the areas of the face that are most informative for further processing of social information. In addition to emotional cues, another salient cue is direct gaze, which elicits heightened activation in the amygdala compared to averted gaze (Kawashima et al., 1999), indicating that the amygdala plays a role in specific aspects of gaze processing.

Second, the amygdala, along with the orbitofrontal cortex, directs retrieval of associated social knowledge about emotions from other neocortical regions and the hippocampus (Adolphs, 2002; Allison, Puce, & McCarthy, 2000; Willis, Palermo, Burke, McGrillen, & Miller, 2010). Furthermore, it also links salient stimuli to the affective response felt by the viewer (Thomas et al., 2001). In this way, the amygdala modulates not only emotional processing but also guides

interpretation of those emotions to form social judgments. Thus, through a variety of mechanisms, the amygdala influences attention to and processing of socially salient stimuli, which in turn influences the further processing of the information conveyed by faces.

Many aspects of social processing that are linked to healthy amygdala functioning are known to be compromised in ASD. Faces are less likely to draw the attention of people with autism, who show reduced orienting and attention to social stimuli (Dawson et al., 2004), less attention to the eye region (Dalton et al., 2005; Klin et al., 2002; Pelphrey et al., 2002), and impairments in processing social and affective information (Harms, Martin, & Wallace, 2010; Schultz, 2005), functions which are associated, at least in part, with amygdala function in neurotypicals. The exact nature of the dysfunction in ASD is unclear, but two plausible explanations include a failure of the amygdala to assign social saliency to faces (Aggleton, Burton, & Passingham, 1980), and a failure of the amygdala to signal feedback pathways that are necessary for processing social stimuli (Schultz, 2005). Nonetheless, while the specific impairments remain an open question, neuroimaging studies in people with ASD do support a general link between abnormal amygdala functioning and social processing impairments, reporting hypoactivation of the amygdala in a range of face perception tasks (Baron-Cohen et al., 1999; Pelphrey et al., 2011; Pierce, Müller, Ambrose, Allen, & Courchesne, 2001; Schultz, 2005). These findings highlighting the importance of the amygdala in social processing, and the impairments that can arise from abnormal functioning have been further validated in studies involving subjects with amygdala lesions.

1.2.7 Amygdala lesion studies

As discussed below, lesion studies have been particularly informative for illuminating the role of the amygdala in social cognition. Amygdala lesion patients demonstrate many similar social processing impairments to those reported in ASD, and there is a great deal of overlap in how both populations view and evaluate faces. For example, amygdala lesion patients demonstrate diminished eye contact (Adolphs et al., 2005; Spezio, Huang, Castelli, & Adolphs, 2007) and greater reliance on information from the mouth rather than the eyes (Birmingham, Cerf, & Adolphs, 2011). Individuals with amygdala lesions are also significantly impaired in recognizing the expression of complex mental states—specifically related to social emotions

such as guilt, admiration, flirting, and arrogance—from both the whole face and from the eyes alone (Adolphs, Baron-Cohen, & Tranel, 2002). Amygdala lesion patients also have deficits in making social judgments regarding traits such as trustworthiness and approachability (Adolphs, Tranel, & Damasio, 1998). A study on a patient referred to as SM who has complete bilateral amygdala lesions found that her impairment in recognizing mental states arises from a failure to *spontaneously* orient to the salient parts of a face rather than from impaired ability to recognize the actual expression (Adolphs et al., 2005). When viewing facial expressions, the proportion of fixations that patient SM would direct to the eye region was atypically low regardless of the emotion. Furthermore, although her recognition of fear was significantly worse relative to controls, this impairment was reversed with a simple instruction to direct her gaze to the eyes.

The findings of the study with patient SM had several implications. First, the results indicated that the amygdala was not necessary for the recognition of emotions. The fact that lesion patients retain a basic capacity to identify basic emotions and show varying degrees of impairment means that there likely exist parallel or redundant pathways for social processing. This also suggests that feedback between those pathways may overlap. Second, the authors interpreted that, while patient SM's gaze behavior was not spontaneous, deficits in emotion perception could be partially mitigated by active evaluation (Adolphs, 2006). The fact that patient SM's recognition of fear could be reversed with top-down control meant that in addition to spontaneously orienting to emotional cues, people can also learn to actively examine faces in order to judge the emotion. These findings also demonstrate that there are multiple pathways for processing of social information.

Given that research has found that the amygdala plays a major role in explaining social processing deficits, especially as it relates to autism, amygdala lesion subjects provide an interesting corollary to better understand the underlying neuroanatomical source of ASD social processing deficits and unimpaired social processing in neurotypicals. Furthermore, studying visual behavior in response to faces in these two clinical populations can tell us about how we evaluate social stimuli, including where we look to gather information, and the role of gaze in social judgments.

1.3 Study Summary and Thesis Structure

In this thesis, I investigate how we arrive at the decision that we like a face and find it attractive. I use eyetracking and self-reported behavioral data to gain insight into the visual behavior that accompanies face gaze and preference decisions in people with autism and amygdala lesions. Along the way, I also explore the use of atypical face gaze strategies in high-functioning autism and amygdala lesion patients. To examine these topics, I utilized a variety of experimental paradigms and measures. In the first two studies, participants performed a 2-alternative forced-choice task. They made preference choices amongst pairs of social stimuli and pairs of non-social stimuli and indicated which image of the pair they preferred (eye gaze was recorded in the "Gaze Cascade" study). In the third study, participants viewed images presented individually on-screen as eye gaze was tracked, and they were instructed to avoid specific salient features of the face. Experiments and participants are summarized in Table 1.1.

Table 1.1. Summary of dissertation structure and participants in studies.

Study	Chapter	Participants			
Eyetracking Algorithm	2	ASD	Matched Controls	Amygdala Lesion	Matched Controls
Gaze Cascade	3a	12	12	3	3
Familiarity versus Novelty	3b	12	12	--	--
Don't Look	4	12	13	3	3

I aimed to answer specific questions in each of the three studies. In healthy controls, we have seen that gaze bias contributes to preference decision-making for both social and non-social

objects. Based on this evidence, in the gaze cascade study I explored whether gaze contributes to social decision-making in autism in the same manner as it does in neurotypicals. That is, to what extent do social processing deficits impair preference judgments about faces? Moreover, do known deficits in objectively evaluating faces also interfere with the temporal evolution of those preference choices? In the second study, "Familiarity versus Novelty," I examined whether intact social processing is necessary for forming a preference bias for familiar versus novel faces. Does a preference for familiar faces develop even in populations with diminished face expertise? In the third and final study, I investigated atypical face viewing strategies. There is evidence to indicate that people with autism—particularly those who are high functioning—compensate for social deficits by using compensatory viewing strategies, which give the general appearance of normal viewing behavior. Based on this evidence, I ask, if people with social processing deficits use atypical face gaze strategies, to what extent are these strategies flexible across different situations (i.e., task demands)? Are they flexible enough to resemble neurotypical viewing behavior even in situations that are not commonly encountered?

My thesis is organized in the following structure. In Chapter I, I discuss social processing in healthy controls and individuals with autism, particularly as it relates to faces and the key brain structures involved in face processing. One of the vital structures that I reviewed is the amygdala, which plays an important role in identifying socially salient information in the environment, and whose function may be compromised in social disorders such as autism. I also discuss sources of heterogeneity in autism that have led to divergent results, underscoring the necessity of developing new ways of identifying and classifying subtypes of autism in the future.

In Chapter II, I review a custom eyetracking algorithm that I developed to address the limited transparency offered by commercially available analysis software, which was used to analyze all eyetracking data presented in this thesis. I also review the types of eye movements that are analyzed in eyetracking studies, present an overview of the most commonly-used analysis filters, discuss how they contribute to extracting relevant eye movement data, and present pseudocode for the algorithm.

In Chapter III, I present the results of two studies examining face preference in which we tested two clinical populations: autism patients and amygdala lesion patients. The first study investigates the link between gaze and face preference formation in autism and amygdala lesion patients, and the second study investigates preference decisions for familiar versus novel faces in autism. I found that individuals with autism and amygdala lesions made similar preference choices as controls in judging face attractiveness and that people with autism demonstrated a similar, yet *faster*, visual sampling process compared to controls. The second study in Chapter III looks at whether social processing deficits affect preference biases for familiar faces over novel faces. We found intact familiarity preferences for faces and novelty preferences for social stimuli in individuals with ASD.

In Chapter IV, I study face viewing strategies decoupled from explicit decision-making in controls and the same two clinical populations—ASD and amygdala lesion patients—and I manipulate face viewing strategies by instructing participants to avoid socially-salient features of the face. I found that individuals with autism exhibit atypical face gaze—and, unlike controls—inflexible viewing strategies. Moreover, amygdala lesion patients showed hints of more subtle abnormalities in face gaze.

In Chapter V, I summarize my findings and discuss the contributions of my work to our understanding of autism and social decision-making. Additionally, I suggest some open questions and future directions for the field.

Chapter II

A CUSTOM ALGORITHM FOR ANALYSIS OF EYETRACKING DATA

2.1 Overview

Eye movements constitute an objective reliable measure of where a person's attention is directed, and as such we can use eye movement recordings as a quantifiable measure of visual and attentional processes involved in social processing tasks. Eye-tracking metrics, such as the number of fixations people make on a feature, or the total dwell time in a region, provide information about what elements of a stimulus attract the most attention, require more processing, or provide the most relevant information. The metrics that are derived from eye-tracking data, however, are highly dependent upon the choice of parameters that are used to define and extract the various eye movements from the raw data, for example, the minimum duration for a fixation, or what amount of spread to allow in successive data points before dividing a fixation into two. Different tools have been developed for the collection and analysis of eye-tracking data. Most commercial eye-tracking systems also come with their own analysis software, and there are many open-source packages available online as well. Unfortunately, commercially-available analysis software cannot be modified beyond a set number of parameters. Beyond this, there is a great deal of processing that occurs in the data collection stage and in the analysis stage that is not easily accessible to the user. Furthermore, the software cannot be modified or used to analyze data collected across different platforms.

So why develop a custom algorithm? First, a custom algorithm is flexible across multiple platforms, accepting eye-tracking data recorded from any system in a simple text file format. This was advantageous for the studies in this dissertation, since data was collected using three different eyetrackers from two different companies, each with their own data parsing steps at the collection stage, and their own filters at the analysis stage. Second, by analyzing all data in this dissertation with the same algorithm, we remove the variance that is introduced by using different analysis software based on the eye tracker used to collect the data. Lastly, a custom algorithm offers consistency and transparency. There is consistency in the filters that were

applied, without the addition of any steps that were unnecessary for our analysis, and the parameters used. Additionally, I understand the necessity of every step of the process from input to output and can explain exactly why my data looks the way it does.

After much research, coding, and trial and error, I determined a combination of filters and settings that was best suited for our data, and for our variables of interest. In this chapter, I introduce the algorithm, discuss the data processing functions that were implemented as filters, and show examples of the algorithm's use.

2.2 Introduction

Eye-tracking research has been growing in popularity in recent years, with researchers using the method to study a variety of visual and cognitive processes including reading, scene perception, face processing, and decision-making. This chapter will introduce a custom algorithm developed for analyzing eyetracking data used in the current study. The algorithm uses a combination of velocity and acceleration thresholds to detect fixations and saccades, and implements filters to address noise and loss of signal in the data stream. We also employ a data-driven methodology to derive threshold values. Many commonly-available software packages, including commercially-available software such as Eyelink and Tobii systems, and open-source codes, use combinations and variations of the methods used in the algorithm we describe here. By testing and tuning each of the individual subcomponents, I gained an understanding of their limitations, and also some insights into the technique of eyetracking itself. The final algorithm thus has components selected and calibrated specifically for my research goals, equipment characteristics, and subject population. This flexible, straight-forward analysis pipeline is suitable for analyzing that data collected across different platforms and in different eye-tracking tasks, and can be further modified and expanded upon based on analysis needs.

In describing the algorithm, I will first review and define various types of eye movements described in the literature. Second, I will discuss the current methods being used to analyze eyetracking data as well as advantages and limitations of those techniques, and finally, I will describe the custom algorithm I developed based in an effort to address some of these limitations. All the eye-tracking data in this thesis have been analyzed using this custom algorithm.

2.3 Defining and Identifying common eye movements

2.3.1 Fixations

In the terminology of vision science, fixations are periods during which the eye remains still or makes minimal movement. During these periods, the brain registers the visual input it receives

and begins to process this information (Irwin, 2004), and as such, fixations are regarded as a metric that can be associated with a number of cognitive functions, including a person's interest, attention, and processing strategies for visual stimuli. Surprisingly, there is no formal consensus as to how fixations should be mathematically defined, though nearly all definitions require that the point of gaze remain in a small spatially restricted area for some minimum amount of time (Lowenthal, 2007). There is little agreement under this definition as to what the specific duration and spatial restrictions should be since there is a range of variability in these measures depending on factors such as task demands, subject population, and the analysis methods that are used derive them. As a result, the specific values are predominantly determined by experimenter preference, the type of study, and the nature of the stimuli. A review of major eye-tracking studies shows that the temporal restrictions generally range from 50 to 500 milliseconds, and spatial restrictions range between one-half of a degree to five degrees of visual angle.

The range of values reflects the range of reasons that researchers use eye-tracking equipment. For researchers interested in oculo-motor mechanisms, even the smallest displacements or pauses may have significance, signifying a series of short fixations in a small region. However, for researchers interested in the visual information that is being gathered by an observer, the sustained inspection of a particular visual detail could be considered a single fixation, even if it involves many tiny movements. This underscores the importance of tuning eye movement algorithms to ones research goals, rather than simply using a generic "industry standard."

2.3.2 Saccades

Saccades are defined as the rapid eye movements that take place in between fixations. During a saccade, eye position, and by extension visual attention, is shifted from one target toward another, and during this shift visual input from the eyes is suppressed. However, saccades are short in duration, lasting from 10 to 40 milliseconds, such that the gap in visual input is generally imperceptible to the human brain and little visual processing takes place. The speed of a saccade is not under conscious control and once underway, the eventual target cannot be changed. Saccades differ quantitatively from fixations in that they have greater spatial dispersion and higher velocity. Consequently, in an algorithm they are usually identified by a

velocity threshold, and in some cases, a concurrent acceleration threshold. Periods during which one or both of these thresholds are surpassed are classified as saccades.

2.3.3 Other eye movements

While fixations and saccades are the primary types of eye movements, there are other types of eye movements, such as smooth pursuit movements, glissades, and blinks (Nyström & Holmqvist, 2010; Purves, 2012). Typically, however, not all movements are relevant to the specific research questions of interest, so algorithms are constructed such that they filter only the types of eye movements that are of interest. Remaining eye movements are classified as either saccades or fixations depending on the choice of thresholds.

2.4 Critical Data Processing Filters and What They Do

2.4.1 Measures used in event detection

At their most rudimentary level, eyetracking algorithms function to differentiate fixations from saccades, which are traditionally identified using a variety of spatial and temporal thresholds. Eyetracking data is recorded in the form of sequential (x,y) gaze position coordinates (see Figure 2.1). From these coordinates, several other measures, such as velocity, acceleration, and dispersion, are calculated that are subsequently used for event detection (e.g. separating fixations from saccades). By comparing the calculated values to spatial and temporal thresholds, these algorithms are able to discriminate fixations from blinks and saccades.

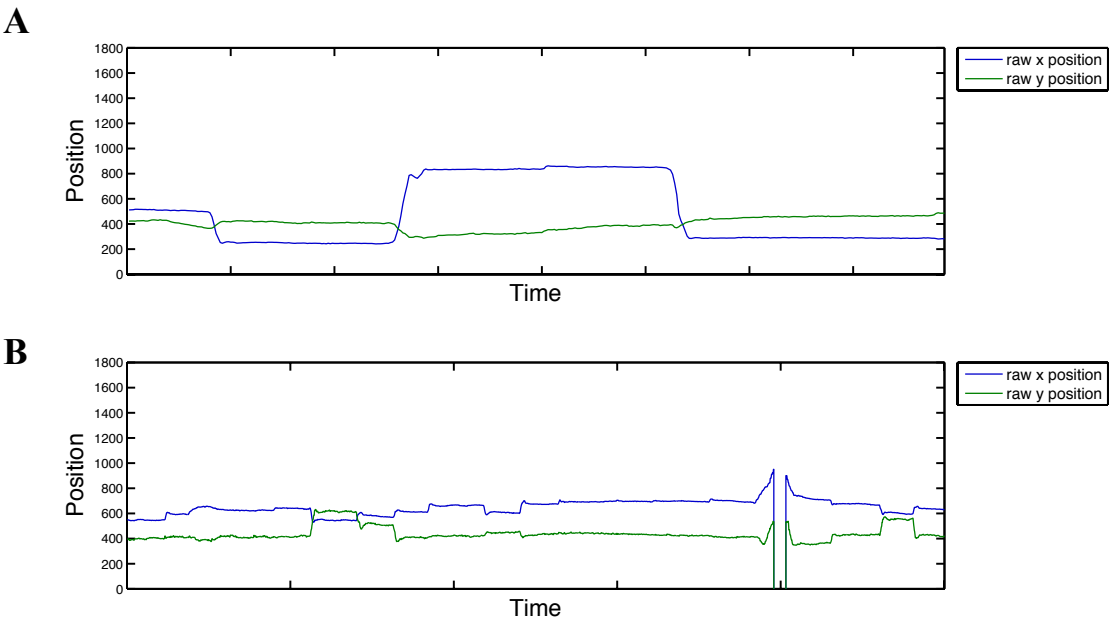


Figure 2.1. Examples of raw eye gaze traces for the x and y position of the right eye recorded at (A) 250 Hz and (B) 500 Hz.

The combination of filters that are implemented and the threshold settings used can dramatically impact the output returned by eye-tracking algorithms, affecting the accuracy of virtually all metrics that are collected (Blignaut, 2009; Shic, Chawarska, & Scassellati, 2008). For example, velocity or acceleration thresholds that are too high can result in short saccades being categorized as part of a fixation. If this occurs, multiple fixations are merged and reported as a single fixation. On the other hand, thresholds that are too low result in noise being categorized as saccades, which will incorrectly break up fixations into multiple smaller ones and even discard them completely. As such, any conclusions drawn from this data would be invalid.

2.4.2 Addressing data quality

Gaze position data contains noise and gaps that must be filtered out in order to get valid and interpretable results. If it remains in the data, noise will negatively affect both the accuracy and

precision of measurements by introducing false position coordinates or erroneous gaps that affect the accurate measurement of fixations and saccades. Noise can be introduced from various sources, including participant movement, the experimental setting, as well as eye-tracking hardware and software. To mitigate the effect of noise on the data analysis, two different types of filters are commonly used: the first seeks to fill in short gaps of missing position data and the second to reduce noise.

Noisy or 'flickery' data (i.e. meaning data containing gaps in the data stream during which the signal was lost) leads to incorrect classification of saccades, affecting both fixation duration and fixation number (Wass, Smith, & Johnson, 2012). If a long fixation is incorrectly split into two smaller ones, and both parts of the fixation are above the minimum duration, the single long fixation will be reported as two short fixations. As a result, the average duration calculation will be shorter and the average number of fixations will be greater than is actually the case. If one or both fixations are below the minimum duration, they would be discarded, resulting in calculations showing shorter and less frequent fixations.

2.4.2.1 Gap fill-in and blink detection

Gaps occur in eyetracking data when the camera briefly loses track of the eye or when a position sample is collected but fails to get relayed due to hardware or software malfunction (Holmqvist, Nyström, & Mulvey, 2012; Olsen, 2012). These types of gaps are usually quite short in duration, ranging from 2 to around 60 milliseconds. If they are allowed to remain in the data, the start of a gap will be incorrectly identified as the end of a fixation, cutting the fixation duration short. Therefore, shorter gaps are filled in with position information from neighboring data points (see Figure 2.2). Gaps shorter than a pre-defined duration are filled in using a weighted scaling factor and the nearest valid samples, using the method described by Olsen and colleagues, and subsequently implemented in the Tobii system (Olsen, 2012). With this method, missing points are interpolated based on proximity to two points: 1) the last valid position sample before the gap and 2) the first valid position sample after the gap. If a missing point is closer to one of these samples than the other, the position of the new point is proportionally weighted to give greater influence to the nearer valid sample. A point positioned

in the middle of the gap is equally weighted by both valid samples, and is equal to the average of the two samples.

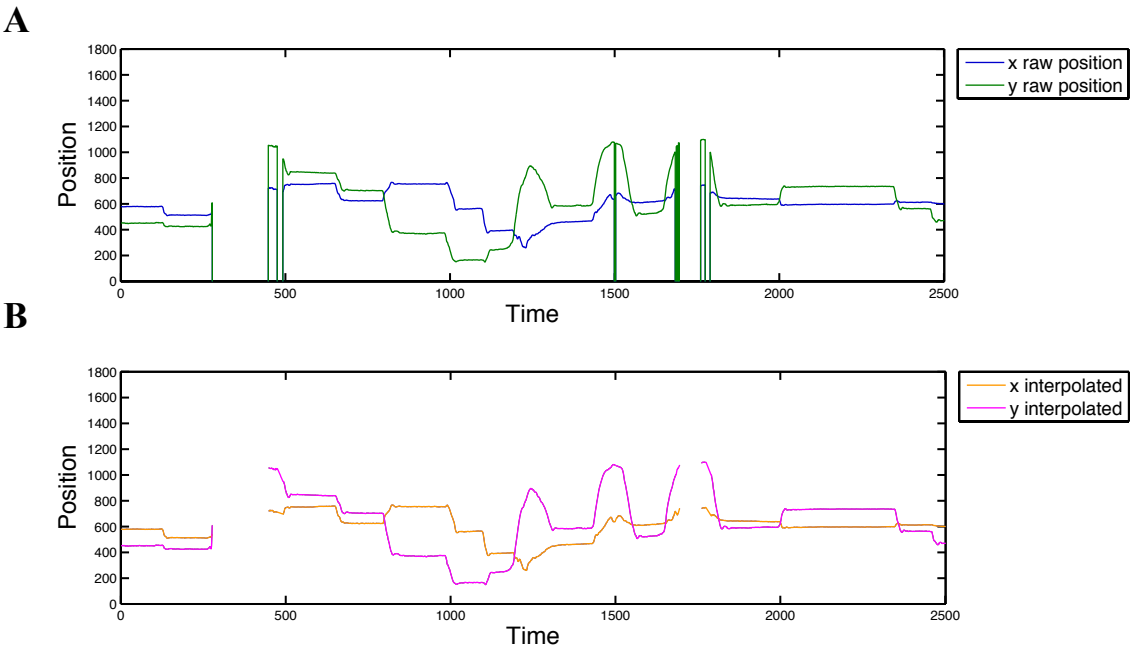


Figure 2.2. Eye gaze traces showing (A) raw gaze data recorded at 500 Hz, and (B) gaze data after gap interpolation has been performed. Gaps are selectively filled based on duration. Note that the smaller gaps (just before 500 ms, at 1500 ms, and at approximately 1750 ms) due to signal loss in (A) have been filled in the traces in (B), but the larger gaps (250-570 ms, and at approximately 1600 ms), which are blinks or gaps that are too large to interpolate without compromising data quality, have been retained.

Blinks also appear as gaps in the data, usually as points where the gaze coordinates and/or pupil size is 0. Gaps due to blinks are longer than those due to hardware or software malfunction, lasting at least 100 milliseconds (Olsen, 2012). For our purposes, we retain blinks as valid gaps rather than interpolate them, so that a fixation interrupted by a blink will be registered as two distinct fixations. To avoid interpolating missing data caused by blinks, the maximum gap duration parameter is chosen so that it is shorter than the duration of a normal blink, roughly 100 milliseconds (Stava, Huffman, Baker, Epstein, & Porter, 1994; VanderWerf, 2003). Gaps that are shorter than this parameter are interpolated, and gaps that are longer remain in the data.

2.4.2.2 Noise reduction

Noise is a significant issue affecting data quality, particularly for high frequency recordings, due to the large number of samples collected per unit of time. However, there is an advantage with high-frequency recordings in that noise can be detected and smoothed with less modification to the data than in low frequency recordings. Noise in the position data artificially increases the distance traveled by the eye from one sample to the next. As a result, the calculated velocity is also artificially inflated, and appears as random spikes in the velocity data stream.

There are a variety of methods that can be used to reduce noise spikes found in time series data, such as a moving average or moving median filter, Savitzky-Golay filtering or loess filtering. We decided to use the "rLOESS" filter, short for "robust locally weighted scatterplot smoothing," because of its flexibility and ease of use. Loess smoothing uses a locally-weighted linear regression and a second-degree polynomial to smooth the data, filtering the x and y dimensions separately (see Figure 2.3). Moreover, the robust version of "LOESS" assigns lower weight to outlier points, reducing distortion of smoothed values (The Mathworks, *Curve Fitting Toolbox: User's Guide*, 2002). There are a few caveats to note when using rLOESS: first, as is the case with other least squares methods, a large number of outliers can still skew results. Second, LOESS can be computationally intensive particularly for large data sets with many trials and subjects, and finally, as is the case with many noise reduction filters, there will be a loss of temporal resolution.

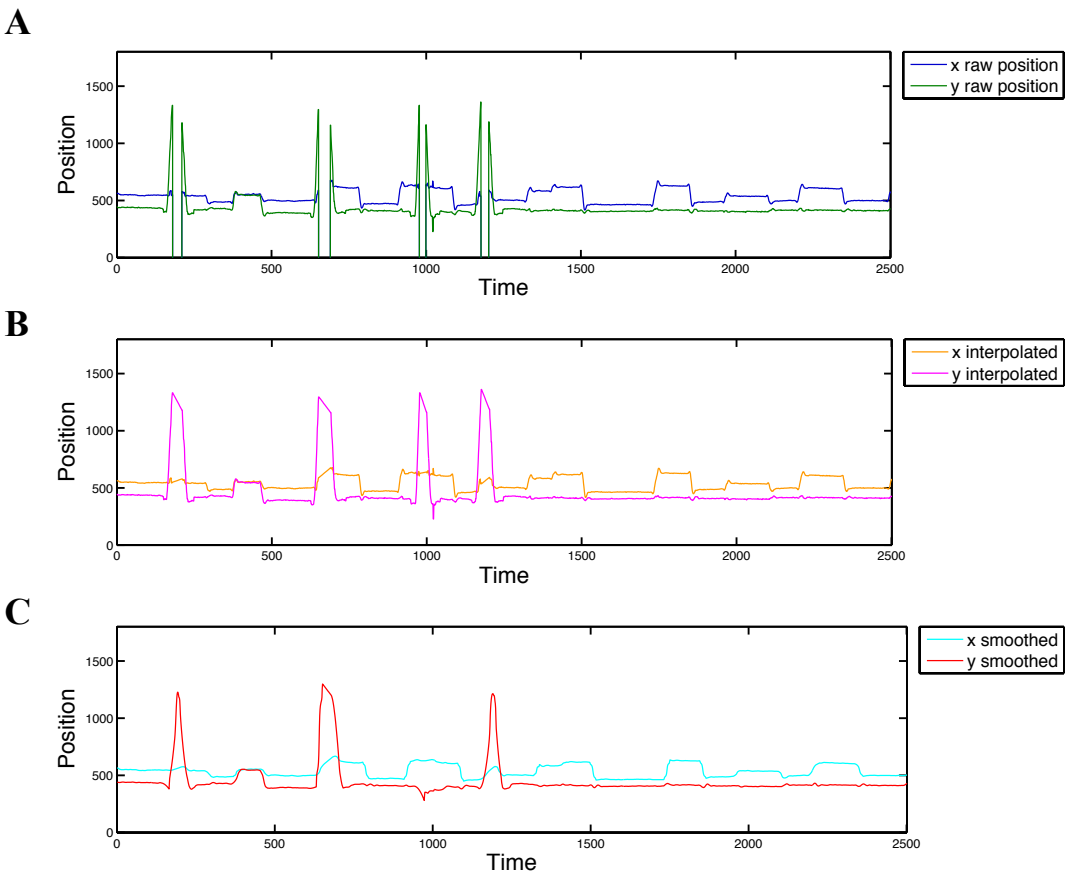


Figure 2.3. Sample gaze data showing the stages of filtering used to address data quality. (A) shows the raw gaze data, (B) shows the same data after gap interpolation, and (C) shows the effect of smoothing interpolated gaze data by applying an "rLOESS" filter for noise reduction.

A symmetric moving window is iterated through the data stream, and the center point in this window is replaced by the new smoothed value. There are several options for how to define the size of this window. Matlab offers the option of setting window size equal to a predefined percentage of the total number of data points. However, the disadvantage of this method is that, all other things being equal, trials of different length will receive different degrees of smoothing. An alternative method is to set the window size equal to a specific number of samples. This, however, leads to different degrees of smoothing when sampling frequency

differs. To allow for comparison of fixation data recorded at different frequencies, we specify a window duration, which is then converted to a specific number of data points before being passed to the Matlab filter. With this approach, a greater number of points are used for smoothing data recorded at a higher frequency, an approach that addresses the larger amount of noise in high versus low frequency recordings.

2.4.3 Separating events (fixations and saccades)

2.4.3.1 Velocity and acceleration calculation

Velocity and acceleration are the measures most often used by common algorithms to define fixations and saccades. While Tobii systems use only a velocity calculation, the Eyelink system uses a combination of both in their algorithm.

In our algorithm, a velocity value and acceleration value is computed for each timepoint in the data stream. Calculating velocity between two consecutive points could potentially introduce a large amount of noise into the data, particularly for higher frequency recordings. Thus, we calculate velocity and acceleration for each point as an average of the neighboring points in a symmetric window, with the point of interest positioned in the middle. This method is similar to the approach used in Tobii systems (Olsen, 2012).

To determine velocity for a sample, the Euclidean distance between the first and last point in the window is calculated and converted into degrees of visual angle, and then divided by the difference in timestamps between the first and last point in the window (see Figure 2.4). Acceleration is computed similarly to velocity, with the exception that the visual angle computation should be replaced with the absolute value of the difference in velocity between the first and last points in the window.

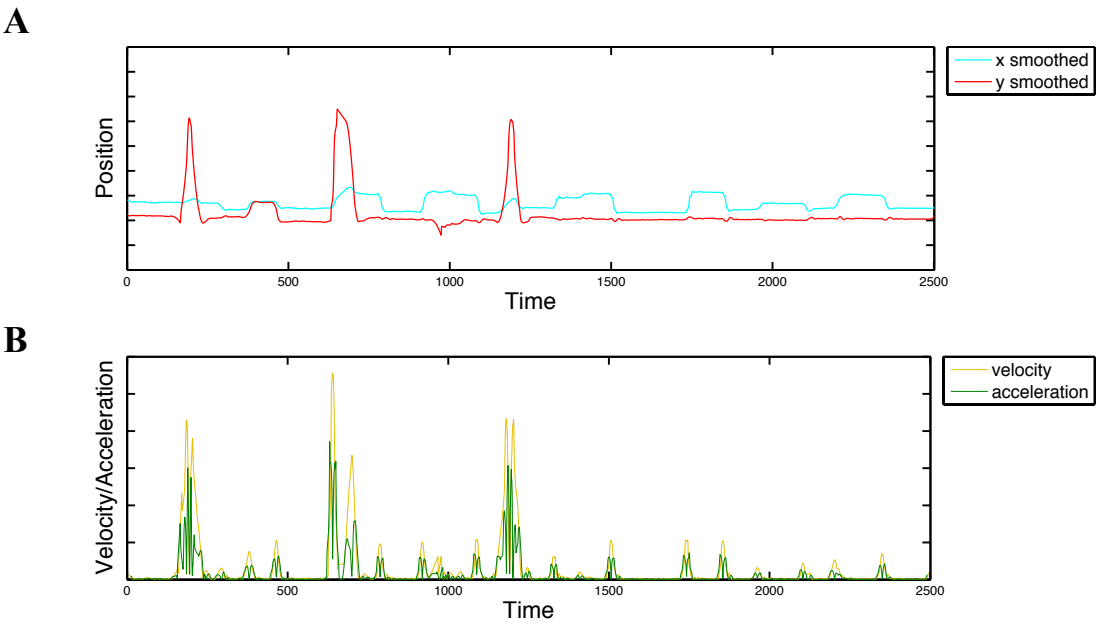


Figure 2.4. (A) Interpolated gaze traces and (B) corresponding velocity and acceleration traces calculated from the interpolated data using a moving average window. Note that for illustrative purposes, velocity and acceleration are not drawn to scale.

2.4.3.2 Determining thresholds

The velocity and acceleration values computed above are compared to threshold values that are calculated separately for each trial (see Figure 2.5). If the velocity or acceleration value is below threshold, the algorithm marks this time point as a potential fixation in the data stream, otherwise it is marked as a potential saccade.

Most fixation detection algorithms use a static threshold that is applied across all subjects and all trials. However, static thresholds do not account for imprecision in the data and several studies have shown that fixation and saccade calculations are highly sensitive to variations in noise levels (Holmqvist et al., 2012; Wass et al., 2012) and may also vary between tasks and individuals (Lans, Wedel, & Pieters, 2010; Rayner, Li, Williams, Cave, & Well, 2007). As a result, if the threshold is too low, noise spikes are mistaken for saccades and fixations are incorrectly split, decreasing fixation durations and increasing the number of fixations. If the

threshold is too high, short saccades are categorized as noise and incorporated into the surrounding fixation, increasing fixation duration and decreasing the overall number of fixations.

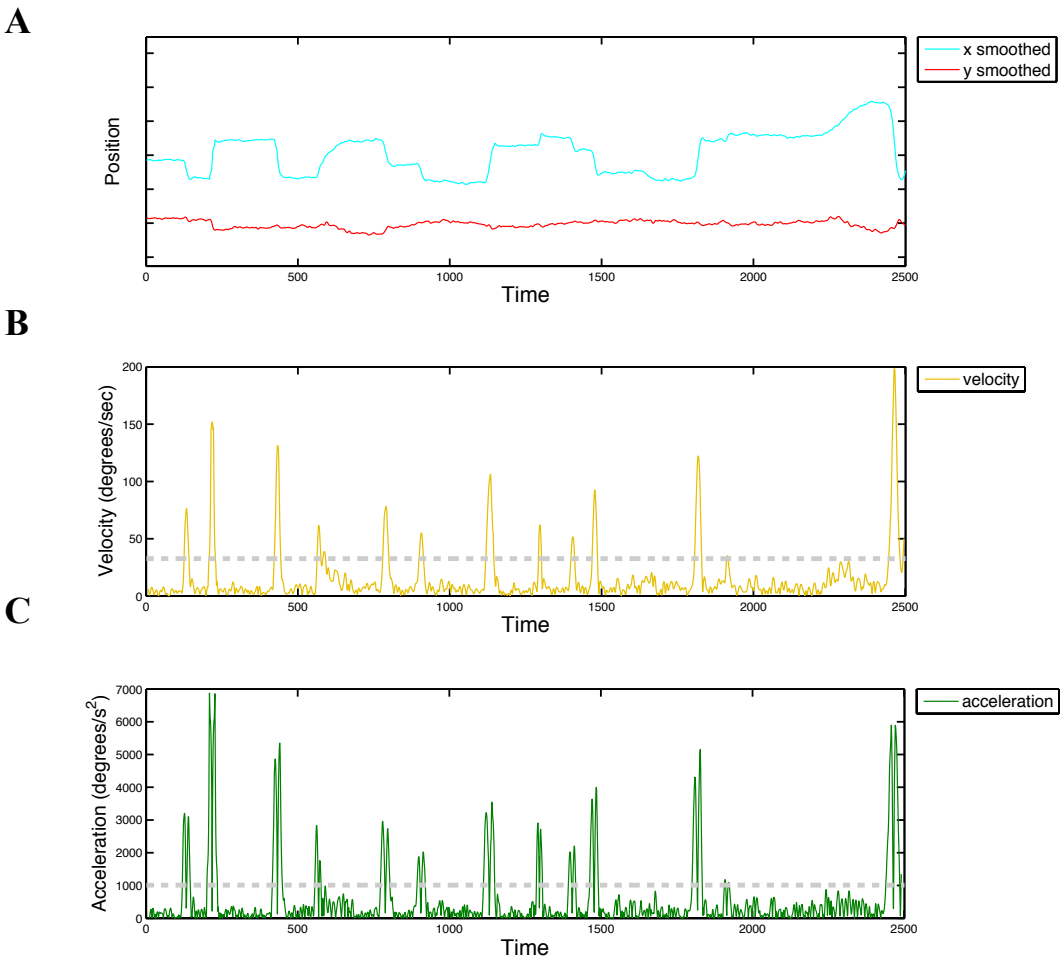


Figure 2.5. (A) Interpolated and smoothed gaze data for one trial, (B) the corresponding velocity trace (gold) and adaptive velocity threshold (dashed gray), and (C) acceleration trace (green) and adaptive acceleration threshold (dashed gray). Velocity and acceleration thresholds are calculated for each trial individually. The saccade detector then checks each data point that exceeds either threshold (i.e. above the dashed lines) to determine if spatial dispersion criteria have been exceeded. If so, the points are marked as a potential saccade. If not, it is re-classified as a fixation point.

In contrast to a static threshold, another method is to use variable thresholds based on the amount of local noise. Adapting the method described by Nyström and Holmqvist (Nyström & Holmqvist, 2010), we used an iterative, data-driven approach to calculate velocity and acceleration thresholds. The strength of this approach is that it takes into account the variability in data quality across subjects and trials and also addresses the issue of differences in characteristics of fixation behavior, rather than using a one-size-fits-all approach that ignores differences across eye-trackers, individuals, and trials.

This is especially important in our case, as we compare data across several eye-trackers and between different subject populations. Tobii, Eyelink II, and Eyelink 1000 trackers sample at different frequencies and have different levels of noise. Participants with high-functioning autism sometimes have more difficulty interfacing with the eye tracker, leading to different levels of noise.

The steps in the adaptive threshold calculation outlined by Nyström and colleagues are as follows: first, the algorithm is given an initial starting threshold that can be any value as long as it lies in the range of observed velocities for that trial. For all samples below this threshold, the mean and standard deviation are calculated. The new threshold is updated by setting it equal to the mean plus a multiplier of the standard deviation. (While Nyström and colleagues found that a multiplier of six was a reasonable value, here we found that a value of three worked best for our data.) Again, the mean and standard deviation of all samples below this new threshold are calculated and the threshold is again updated. This process iterates until the new threshold is less than one degree per second greater than the previous threshold for velocity.

2.4.3.3 Displacement calculation

In addition to velocity and acceleration thresholds, a motion (or displacement) threshold is also used to delay saccade onset until the eye has moved a minimum distance out of the most recent fixation. This filter is similar to one implemented by Eyelink systems and adds an additional layer of security against false saccade onset. While this calculation can be performed a number of different ways, here we calculate the distance between each potential saccade point and the nearest preceding fixation point to determine whether displacement since the previous fixation exceeds threshold.

2.4.3.4 Saccade detector

The saccade detector makes two passes through the data stream, once before the motion calculation and once after. In the first pass, the detector checks the velocity and acceleration of each individual sample against the data-derived thresholds (see Figure 2.5 above). If either velocity or acceleration exceeds threshold, the point is marked as a potential saccade. Otherwise, the point is marked as a potential fixation. After performing the motion calculation described below, the saccade detector makes a second pass through the data stream, checking each point marked as a potential saccade against the displacement threshold. If this threshold is not surpassed, then the point likely belongs to the most recent fixation and it is re-classified as a fixation.

2.4.4 Rejecting false saccades and fixations

2.4.4.1 Saccade classifier

As added insurance against imprecision in the data, the saccade classifier is triggered only when there have been a sufficient number of sequential samples identified as potential saccades, followed by a specific number of samples identified as potential fixations (see Table 2.1 below). This filter makes it so that the classifier is not activated by short, alternating periods of fixation and saccade points that remain in the data despite filtering.

Table 2.1. Illustration of the saccade classifier filter. Potential saccade points are marked as zeros, and potential fixations as ones. In the example below, the minimum number of saccade points that must appear sequentially is two, and the minimum number of fixation points is 5, such that the saccade classifier does not signal the start of a saccade until a minimum fivef two saccade points appear sequentially, after which the saccade signal does not turn off again until the minimum number of fixation points appear sequentially.

Pre-Filter Classification	***Post-Filter Classification***
1	1
1	1
0	1
1	1
0	1
0	1
1	1
0	1
0	1
0	0
0	0
0	0
1	0
0	0
0	0

2.4.4.2 Merging fixations

Despite addressing data quality issues with gap interpolation and noise smoothing, there will still be gaps in the data that cause fixations to be incorrectly classified as multiple smaller ones. Other studies have shown the most accurate results are obtained if this step is performed near the end of the data processing pipeline. Consequently, in our algorithm we implement this filter in the second to last step, before short fixations are discarded.

To address the issue of incorrectly split fixations, consecutive fixations are checked to determine whether they are spatially and temporally close. If both these criteria are met, it is highly likely the two fixations were originally part of one larger fixation. These fixations are subsequently merged on the basis of two criteria: the time interval between the fixation groups must not exceed a pre-defined duration threshold and the distance between fixation groups must not exceed a pre-defined spatial threshold.

2.4.4.3 Discarding short fixations

Lastly, fixations with durations shorter than the minimum duration are discarded. While there is no consensus for how short a fixation can be, most studies use a bottom duration limit of 50 to 100 milliseconds. See Figure 2.6 for the outcome of algorithm after merging fixations and discarding of fixations that do not meet the minimum duration threshold.

2.5 Conclusion

In summary, this algorithm employs a combination of velocity and acceleration thresholds to detect fixations and saccades, implements an rLOESS filter to address noise, and interpolates missing points due to signal loss in the data stream. We also employ a data-driven methodology to derive threshold values. This flexible, straight-forward analysis pipeline is suitable for analyzing that data collected across different platforms and in different eye-tracking tasks, and can be further modified and expanded upon based on analysis needs.

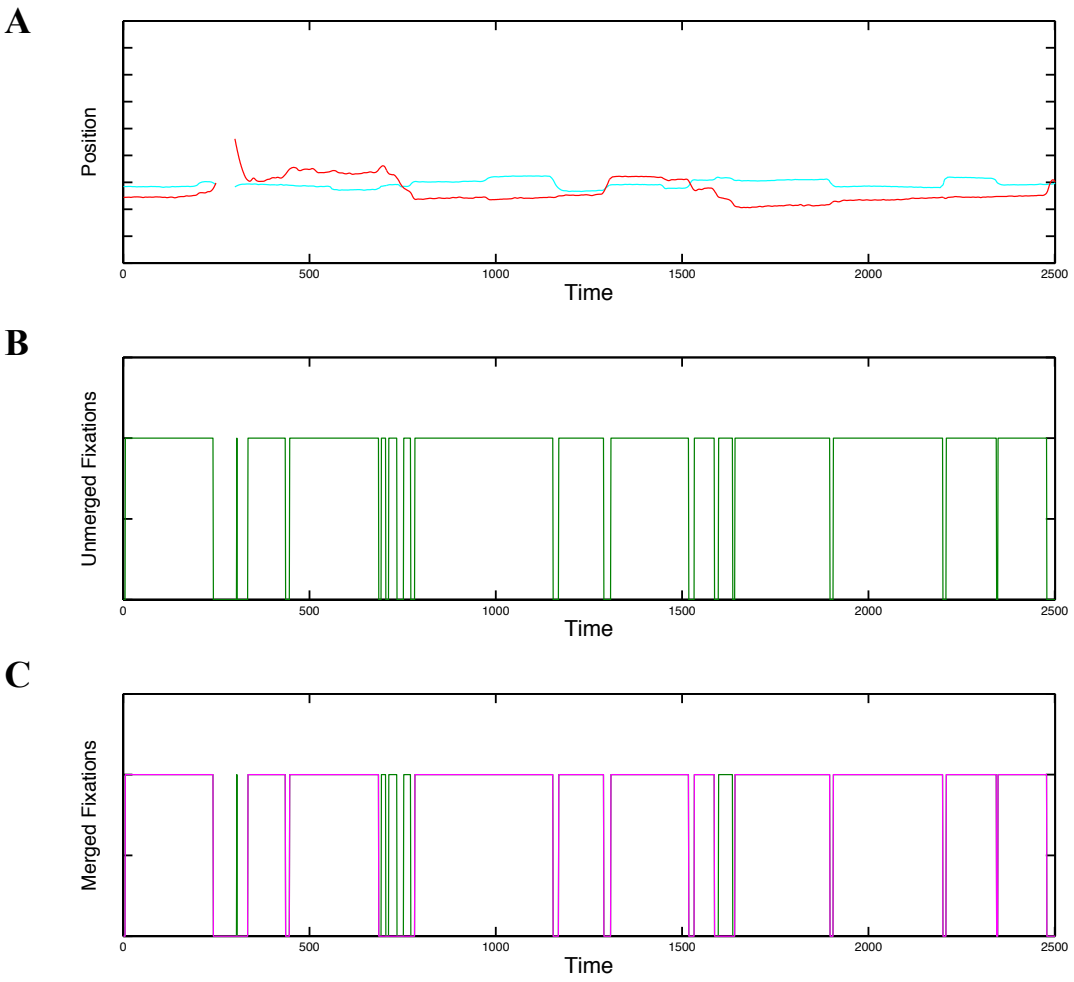


Figure 2.6. (A) Interpolated data, (B) corresponding fixation output showing fixations with no minimum duration, (C) final fixation classifier output (purple) and discarded fixations (green).

2.6 Pseudocode of Event Detection Algorithm

1. Filtering & de-noising

    a. Identify gaps in the data stream where eye position data is missing.

b. Separate gaps that are longer than the maximum gap duration parameter from gaps that are shorter. Gaps that are longer than this parameter are retained as valid gaps. Gaps that are shorter than this parameter continue to the next step for interpolation.

c. Interpolate each data point in the gap separately, using the last valid data point before the gap begins (t_1), the first valid data point after the gap ends (t_2), and a scaling factor (α).

   i. Scaling factor (α): Subtract the timestamp at t_2 from the timestamp of the point being replaced (t^*), and then divide by the total duration of the gap ($t_2 - t_1$). Namely, define:

$$\alpha = (t_2 - t^*) / (t_2 - t_1)$$

   ii. Multiply the scaling factor by the position data at *t1* ($x(t_1)$).

   iii. Subtract the scaling factor from 1, and multiply by the position data at *t2* $x(t_2)$. Add this result to the result from the previous step for the new interpolated position coordinates ($x(t^*)$), such that:

$$x(t^*) = \alpha\, x(t_1) + (1-\alpha)\, x(t_2)$$

   iv. Repeat for each point until all missing points in the gap are interpolated.

   v. Repeat steps i-iv for each gap in the data stream.

d. Iterate a moving window through the data stream, calculating a local regression for each data point using the "rLOESS" function in Matlab.

2. Calculation of adaptive thresholds

   a. Velocity calculation: Iterating a moving window through the data stream, determine angular velocity for each sample; calculate the Euclidean distance between the first

and last points in the window, and then convert the distance to degrees of visual angle. Next, divide the visual angle by the difference in timestamps to get angular velocity for the data point.

   b. Acceleration Calculation: Repeat the same method as above to determine acceleration for each sample, with the modification of replacing Euclidean distance with the difference in velocity between the first and last samples in the window.
   c. Calculate adaptive thresholds for velocity and acceleration using the method described in the text.

3. Saccade detection & classification
   a. Compare velocity and acceleration of each data point against the thresholds and mark as a potential saccade if either threshold is exceeded. Otherwise, mark the point as potentially belonging to a fixation.
   b. Motion Calculation: For each potential saccade point, calculate the motion travelled from the most recent fixation point. If this distance does not exceed the motion threshold, re-classify point as a fixation.
   c. Moving through the data stream, mark the saccade detector as active for any data point for which the motion threshold is exceeded and either velocity or acceleration exceeds threshold.
   d. Classify saccades as periods where the saccade detector has been on and off for the minimum number of samples. All other points marked by the saccade detector are considered noise, and should be classified as samples belonging to fixations.
4. Fixation identification
   a. Calculate the distance and timestamp difference between sequential fixations.

b. If neither the spatial nor the temporal threshold for merging fixations is exceeded for a pair of fixations, then merge the fixations into one.

c. Discard fixations that do not meet the minimum duration parameter.

2.7 Summary of Suggested Parameter Settings

Filtering Step	***Parameter***	***Value***
Gap Fill-in	Maximum Gap Duration	75 ms
Noise Reduction	Filter	Robust loess (rLOESS in Matlab)
Noise Reduction	Filter Window Duration	40 ms
Velocity Calculation	Velocity Window Duration	22 ms
Acceleration Calculation	Acceleration Window Duration	22 ms
Calculating Thresholds	Velocity and Acceleration Threshold	*Adaptive*
Motion Calculation	Motion Threshold	0.45 degrees
Saccade Classifier	Minimum Samples for Saccade On	2
Saccade Classifier	Minimum Samples for Saccade Off	5
Merging Fixations	Maximum Angle between Fixations	0.5 degrees
Merging Fixations	Maximum Time between Fixations	75 ms
Discarding Fixations	Minimum Fixation Duration	100 ms

Table 2.2. Suggested initial parameter settings for eye-tracking data recorded at 500 Hz.

Chapter III

FACE PREFERENCE DECISION-MAKING AND VISUAL BEHAVIOR

3.1 Overview

Now that the methodological structure for analysis of the eyetracking data in Chapter II has been discussed, the attention should be turned to the empirical studies in this thesis. Chapter III is composed of two studies that examine face preference and visual behavior. In these studies, we tested people with autism spectrum disorder (ASD) and amygdala lesion patients to address two important questions regarding social processing: 1) do known deficits in objectively evaluating faces also interfere with making subjective decisions about faces? And 2) are the visual behaviors that accompany face preference decisions in controls the same in people with social processing deficits?

There is considerable evidence for abnormal social processing in people with ASD, specifically in the context of objective decision-making, such as identification of familiar faces and recognition of emotional expressions. It remains unknown, however, whether reported deficits in social processing also extend to making preference-based decisions amongst social stimuli, such as those regarding face preference or attractiveness. The aim of the studies in this chapter was to explore the extent to which these known aberrations in social processing interfere with preference decision-making.

We present two studies in ASD and amygdala lesion patients that investigate whether preference decisions for faces are altered in these conditions. Both studies utilized a 2-alternative forced-choice task in which subjects inspected pairs of face stimuli or pairs of non-face stimuli and made a decision about which stimulus they prefer.

In the first study in this chapter, the "Gaze Cascade" study, we examined the link between gaze and preference formation in people with ASD and amygdala lesions. Specifically, we were interested in investigating whether reported deficits in social processing influence the *temporal*

evolution of preference-based decisions among social stimuli, as well as the eventual outcome of those preference-based decisions. Furthermore, we sought to examine whether the eye movements of people with ASD and amygdala lesions would indicate a fundamentally altered evaluation process when deciding among social stimuli.

In the second study, the "Familiarity versus Novelty" study, we examined the evolution of *category-specific preference biases* by investigating in high-functioning autism a principle reported in the literature for neurotypicals: the preference for familiar faces over novel faces. We have seen that repeated visual exposure to a face increases preference for that face, and that the effect is likely linked to how we acquire and develop face expertise. But what happens in a population, such as people with autism, who demonstrate impairments in developing face expertise? In this study, we explored established preference principles for social and non-social stimulus categories that have been observed in controls.

We found that people with ASD and amygdala lesion patients made similar preference decisions as controls in judging face attractiveness in the "Gaze Cascade" study, and that people with ASD demonstrated similar preference biases and visual orienting as controls in the "Familiarity versus Novelty" tasks. In addition, both ASD and amygdala lesion patients demonstrated a similar visual sampling process, linking preference and attentional orienting. However, people with ASD displayed two key differences compared to neurotypicals: the ASD group was significantly faster in making preference decisions, and reaction times in the ASD group were insensitive to decision difficulty, particularly for social preference decisions.

We suggest that the known perceptual advantage in ASD, coupled with the absence of higher-order social attributions and diminished interest in social stimuli in ASD, could confer a response time advantage to the ASD group in the face preference tasks. Evidence in the literature is consistent with this possibility and we discuss these points in the Discussion. Furthermore, it could also be the case that face preference formation is not significantly impaired by the alterations in observed face processing or perhaps even social processing, given that subjective attractiveness judgments do not require the retrieval of social knowledge or high-order mentalizing.

That the ability to form social preferences remains intact in a clinically diagnosed population with putative deficits in social processing suggests that social preference formation is an aspect of social processing that operates by way of a different or perhaps similar but less complex underlying cognitive mechanism than other aspects of social processing. The results contribute to the growing literature, showing that many basic elements of social processing are spared or compensated for, and that social processing impairments in high-functioning autism become more prominent during higher-order complex judgments that require linking perceptual information with relevant social knowledge. In other words, impairments in social cognition that occur earlier in the processing stream could be compensated for, or simply not relevant to, some aspects of social functioning. Indeed, the results from the gaze cascade study and familiarity/novelty studies in this chapter indicate that the mechanism linking gaze to preference formation for faces, and the ability to form preferences about faces as well as maintain those preferences, appears intact in ASD. However, we also discuss evidence that there are underlying differences in the behavioral strategy used by individuals with autism.

The gaze cascade study in ASD has been published as (Gharib, Mier, Adolphs, & Shimojo, 2015). Daniela Mier also assisted with data collection in the Familiarity versus Novelty study.

3.2 Gaze Cascade Study in Autism

3.2.1 Abstract

People with autism spectrum disorder (ASD) have been reported to show atypical attention and evaluative processing, in particular for social stimuli such as faces. The usual measure in these studies is an explicit, subjective judgment, which is the culmination of complex-temporally extended processes that are not typically dissected in detail. Here we addressed a neglected aspect of social decision-making in order to gain further insight into the underlying mechanisms: the temporal evolution of the choice. We investigated this issue by quantifying the alternating patterns of gaze onto faces, as well as nonsocial stimuli, while subjects had to decide which of the two stimuli they preferred. Surprisingly, the temporal profile of fixations relating to choice (the so-called "gaze cascade") was entirely normal in ASD, as were the eventual preference choices. Despite these similarities, we found two key abnormalities: people with ASD made choices more rapidly than did control subjects across the board, and their reaction times for social preference judgments were insensitive to choice difficulty. We suggest that ASD features an altered decision-making process when basing choice on social preferences. One hypothesis motivated by these data is that a choice criterion is reached in ASD regardless of the discriminability of the options.

3.2.2 Introduction

Autism Spectrum Disorder (ASD) is a pervasive developmental disorder characterized by impairments in social and cognitive processing. One of the core diagnostic criteria for this disorder is a deficit in social communication and social interaction (DSM-V), which presents in real-life interactions as an inattention to faces and reduced eye contact, in addition to more complex social deficits such as difficulty recognizing emotional expressions and relating to others. Several hypotheses propose that motivational or attentional social deficits in early life could disrupt a critical phase in normal brain development, during which early social orienting typically lays the framework for more complex social and cognitive processes to develop later in life (Chevallier, Kohls, Troiani, Brodkin, & Schultz, 2012; Dawson et al., 2004; 2002). In people with ASD, these early-onset motivational deficits may cause reduced social orienting

and learning from a young age, resulting in decreased attending to social stimuli, which further disrupts normal development of cognitive processes related to social perception (Mundy & Neal, 2000).

A large number of studies examining these social impairments have found a reduced attentional bias towards faces in ASD. When viewing complex social scenes, people with autism make fewer initial fixations to the person and to the face within a scene relative to controls, indicating thatthere is reduced spontaneous attentional capture by social stimuli (Fletcher-Watson et al., 2009). Similarly, in a selective attention task for which controls are unable to ignore irrelevant faces, people with ASD were found to be un-distracted, leading the authors to suggest that a deficit in the automatic processing of faces may underlie the diminished attentional bias for faces (Remington et al., 2012).

In addition to the reduced saliency of faces for people with autism, many studies have found that when people with ASD *do* fixate on faces, the pattern of visual behavior with respect to facial features differs from neurotypical viewing behavior. The exact nature of these differences, however, is far from clear. Some studies report reduced gaze to the eyes and increased reliance on information in the mouth region (Klin et al., 2002; Spezio, Adolphs, Hurley, & Piven, 2007), while other studies that similarly report reduced gaze to the eyes find little difference in gaze to the mouth region (Corden et al., 2008; Dalton et al., 2005). Pelphrey and colleagues even reported reduced fixation time to *all* socially-salient regions of the face, including the eyes, nose, and mouth, and increased gaze to non-feature regions of the face (Pelphrey et al., 2002). The variable results have been attributed to a number of factors, including experimental differences in stimulus type (e.g., static/dynamic, computer-generated/real faces) and task demand (e.g., emotion judgment, gaze direction, etc.). However, a growing number of studies also propose that discrepant results arise, in part, due to the use of compensatory mechanisms or atypical processing strategies during certain types of face perception tasks, particularly by individuals who are high-functioning (Harms et al., 2010; Joseph & Tanaka, 2003; Rice, Moriuchi, Jones, & Klin, 2012; Rutherford & McIntosh, 2006).

Abnormal gaze behavior in ASD is often accompanied by difficulties evaluating social information conveyed by faces, such as recognizing emotional expressions. Again, the findings are inconsistent, but some behavioral studies have found impaired recognition of basic emotions in ASD: compared to their neurotypical counterparts, people with autism are slower and less accurate in identifying certain negative emotional expressions such as anger, fear, and sadness (Ashwin et al., 2006; Bal et al., 2009; S. Wallace et al., 2008), though basic emotion recognition might still be preserved in high-functioning individuals (Castelli, 2005). There is stronger evidence, however, in support of impairments recognizing complex emotions, such as jealousy and trustworthiness, and making higher-level social judgments from faces that involve attributions of mental state (Adolphs et al., 2001; Baron-Cohen et al., 1997). Moreover, deficits in the ability to recognize facial expressions of emotions such as fear (Pelphrey et al., 2002) and sadness by people with ASD (Corden et al., 2008) are correlated with abnormal gaze to central features of the face, and particularly the eyes.

Two highly relevant aspects of social processing have, however, not been much investigated: our preference decisions among social stimuli, and the temporal evolution of preference-based choices. First, most of the research on face processing to date focuses on emotion recognition or face perception in general, and few studies have investigated how these factors can influence our preferences of faces. Thus far, much of the research examining visual behavior in ASD has focused on atypical visual behavior and the nature of these impairments specifically in the context of objective decision-making, such as correctly identifying emotional expressions. What is unknown, however, is whether these reported deficits also extend to making more subjective decisions, such as those involving face preference or attractiveness, which are just as relevant to social functioning, perhaps even more so. Secondly, it remains unknown how abnormal social judgments about faces might arise—what is the timecourse and possible underlying mechanism as atypical choices unfold?

Previous studies in typically developed individuals have investigated the cognitive processes involved in making preference choices. One class of models is known as drift diffusion models (DDM) and was initially proposed by Ratcliff and colleagues to describe two-choice decision processes (Ratcliff, 1978; Ratcliff & McKoon, 2008). These models assume that evidence for

each alternative is accumulated and integrated over time until a decision threshold is reached. More recent studies have shown that integrating eyetracking data as an additional parameter in the DDM results in a model that better predicts choice and possibly reaction times (Krajbich, Armel, & Rangel, 2010).

Similar in form to the drift diffusion models is the gaze cascade phenomenon proposed by Shimojo and colleagues (S. Shimojo, Simion, Shimojo, & Scheier, 2003), emphasizing the behavioral dynamics of preference choice. In their model, it is proposed that preference and gaze mutually interact in a positive feedback loop to produce an effect known as a "gaze cascade." Given a choice between two stimuli, individuals are initially just as likely to inspect one image in the pair as the other. However, in the few seconds before a preference decision is made, an increasing gaze bias occurs toward the eventually-chosen stimulus. Shimojo and colleagues propose that in the moments before this decision is made, a positive feedback pathway is engaged in which the gaze bias towards the to-be-chosen image leads to increased preference, which in turn increases gaze bias further, and so on, until the preference signal surpasses threshold leading to a behavioral decision. Thus in this model, gaze orienting is intrinsically linked to and necessary for decision-making and vice versa. Indeed, further evidence supporting the reciprocal effect of gaze on preference formation is demonstrated in experiment 2 of the same paper and a follow-up study using fMRI (Ito et al., 2014). In both studies, one face in a pair is presented on screen for a longer duration than the other face. After several repetitions, participants report a preference bias for the longer-presented face, indicating that manipulation of gaze can directly influence preference decisions. While the gaze cascade effect has been observed in other studies examining preference choice (Noguchi & Stewart, 2014; C. Simion & Shimojo, 2006), the effect may also extend to other types of visual decision-making tasks (Fiedler, 2012; Glaholt & Reingold, 2009; Wiener, Hölscher, Büchner, & Konieczny, 2011).

Given that the literature suggests atypical viewing behavior in ASD is accompanied by deficits in processing social information, the current study sought to examine the influence of gaze on preference choice in autism and, specifically, whether eye movements reveal a fundamentally different evaluation process in ASD. Eye-tracking was used to investigate gaze behavior in

adults with high-functioning autism while they made preference decisions amongst pairs of social and non-social stimuli. Since direct gaze can elicit atypical visual behavior in ASD, we utilized face stimuli depicting open eyes as well as closed eyes so that we could determine whether a potentially abnormal "gaze cascade" effect was caused by an avoidance of direct gaze, or rather by an overall difficulty in making self-paced preference judgments for faces. Furthermore, we tested whether the typically robust gaze cascade would remain intact under time pressure by using a time restriction in one block. Consistent with evidence that individuals with ASD have difficulty evaluating and making social judgments about faces, and given evidence of reduced attention to faces and direct gaze in ASD, we predicted that the ASD group would not have a normal gaze cascade, take longer than controls to make preference choices regarding faces, and end up making unusual preference choices. To our surprise, we found an essentially typical gaze cascade, normal final preferences, and faster decision times in ASD.

3.2.3 Materials and methods

3.2.3.1 Participants

Participants were a group of 12 high-functioning subjects with a DSM-IV diagnosis of Autism Spectrum Disorder (M_{age} = 35.4 years, SD = 12.8, age range = 22-58; Females = 3). Sample size was determined by participant availability. Diagnosis was confirmed by ADOS [Autism Diagnostic Observation Schedule, (Lord et al., 2000)] and ADI-R [Autism Diagnostic Interview-Revised, (Lord, Rutter, & Le Couteur, 1994)] or SCQ [Social Communication Questionnaire, (Rutter, Bailey, & Lord, 2003)]. The comparison group consisted of 12 healthy controls (M_{age} = 33.3 years, SD = 11.9, age range = 20-59; Females = 1), group-matched for age, gender, and IQ, with no family history of psychiatric illness. Table 3.1 summarizes demographic and diagnostic information for participants.

Independent samples t-tests showed that the groups were not significantly different in terms of age ($t(22) = 0.44$, $p = .685$), gender ($p = .590$, 2-sided Fisher's Exact Test), and IQ ($t(22) = -0.87$, $p = .392$), as measured by the Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999). All participants gave written informed consent to participate under a protocol approved by the Institutional Review Board of the California Institute of Technology.

Table 3.1. Demographic and diagnostic information for autism and control participants in the gaze cascade study.

	Autism group			Autism group: ADOS	
	Age	*Verbal IQ*	*Full scale IQ*	*SOC*	*COM+SOC*
1	58	118	126	7	9
2	24	118	101	7	12
3	22	102	107	14	21
4	22	101	102	13	20
5	42	80	93	14	20
6	30	111	106	11	17
7	57	119	102	8	12
8	31	127	124	7	11
9	26	89	93	7	10
10	47	109	104	7	9
11	29	117	115	14	20
12	37	135	133	9	13
Mean	35.4	110.5	108.8		
SD	12.8	15.5	12.9		
	Control group				
	Age	*Verbal IQ*	*Full scale IQ*		
Mean	33.3	111.7	113.1		
SD	11.9	11.7	11.3		

a. Verbal IQ and full-scale IQ from the Wechsler Abbreviated Scale of Intelligence; ADOS: Autism Diagnostic Observation Schedule; SOC: social interaction subscale; COM+SOC: communication + social interaction subscales.

3.2.3.2 Stimuli and apparatus

Stimuli consisted of pairs of social stimuli (computer-generated human faces) or pairs of non-social stimuli (nature scenes sourced from a google image search for “desert” and “mountain”).

Face images, generated using Facegen (Singular Inversions, Vancouver, Canada), were front-facing with neutral emotional expression and direct eye contact.

To control for gaze bias due to differences in baseline attractiveness of the stimuli, all images were drawn from a larger set of face and nature scene stimuli pre-rated for attractiveness by a separate group of non-autistic participants on a scale of 1 (very unattractive) to 7 (very attractive) (n = 20, Females = 8; M_{age} = 28.2 years, SD = 7.5). In accordance with the original gaze cascade study, images were then selected and paired such that half the pairs in each block had images that were equal in attractiveness pre-ratings ("high difficulty" trials) and the other half had a difference of 1.5 points ("low difficulty" trials). Each image pair was presented in randomized order once per block, and the location of each image in a pair was left-right randomized. The two Open Eyes blocks and the Roundness block (see Figure 3.1) used the same set of faces. For a further condition with a stricter time restriction, we created a novel set of face stimuli from the images that had been pre-rated by the same participants, in order to eliminate memory effects. Image pairs in the Timed condition had the same mix of "high difficulty" and "low difficulty" trials as the untimed conditions.

Images were presented on a 21" CRT monitor with a refresh rate of 100 Hz and pixel resolution of 1152 x 864. The stimuli in each test pair were presented simultaneously on the left and right side of the screen. At a viewing distance of approximately 57 cm, each stimulus pair had an overall size of 36.2 (width) x 14.4 (height) degrees of visual angle.

Stimuli were presented using Matlab (Mathworks, Natick, MA), the Psychophysics toolbox (Brainard, 1997), and the Eyelink toolbox (Cornelissen, Peters, & Palmer, 2002). Gaze data was collected using a head-mounted Eyelink II eye-tracking system (SR Research, Osgoode, Canada). Corneal and pupil reflection were recorded at a sampling rate of 250 Hz. At the beginning of each block, a 9-point calibration was performed. Each trial began by requiring subjects to fixate on a central drift correction dot. After the eye-tracker registered a successful fixation, participants pressed the space bar to start the trial.

3.2.3.3 Procedure

Subjects performed various 2-alternative forced-choice (2AFC) tasks while eye-gaze was tracked (see Figure 3.1). Subjects inspected a pair of simultaneously presented stimuli, then made the 2AFC choice by pushing either the left or right button. In advance of the experiment, subjects completed 20 trials with simultaneously-presented geometrical shapes in which they had to indicate which of the two was a triangle. This task was implemented to check for basic motor response time differences between groups.

Experimental design consisted of five blocked conditions where either the stimulus or task instruction was varied (see Figure 3.1 for summary of experimental conditions and sample stimuli). In three of the blocks, participants made self-paced preference decisions, viewing either faces with open eyes (Open Eyes), faces with closed eyes (Closed Eyes), or nature scenes (Nature Scenes), reporting which face (or nature scene) they liked the most. In another block, participants viewed open-eyed faces but instead made objective decisions as to which face was rounder (Roundness), again with no time limit. In the fifth block, participants viewed open-eyed faces and made preference decisions, but were given only 1.5 seconds for each decision (Timed). All blocks consisted of 40 trials, with the exception of our main condition of interest, Open Eyes, which consisted of 80 trials. Block order was counter-balanced across subjects.

Lastly, we selected a subset of the images presented in the experiment (13-14% of all images) that had been given low, average, and high attractiveness pre-ratings and had all participants rate this subset for attractiveness on a scale of 1 (very unattractive) to 7 (very attractive).

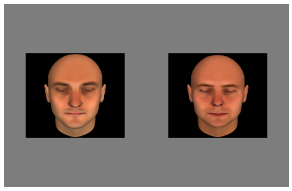
Condition Name	Stimuli Description	Example Stimuli	Time per Trial	Decision Type
Open Eyes	Faces with Open Eyes		Self-paced (2 x 40 trials)	Preference Judgment
Closed Eyes	**Faces with Closed Eyes**		Self-paced (40 trials)	Preference Judgment
Timed	Faces with Open Eyes		**1.5 seconds** (40 trials)	Preference Judgment
Roundness	Faces with Open Eyes		Self-paced (40 trials)	**Objective Judgment**
Nature Scenes	**Nature Scenes**		Self-paced (40 trials)	Preference Judgment

Figure 3.1. Summary of experimental conditions and example stimuli.

3.2.3.4 Analyses

Data were analyzed using custom scripts written in Matlab. In the four preference decision conditions (Open Eyes, Closed Eyes, Timed, and Nature Scenes), high difficulty trials were compared to low difficulty trials (as defined above in Stimuli & Apparatus). For the objective Roundness condition, we defined difficulty by calculating a height to width ratio for each face,

and then ranking the stimulus pairs according to face ratio differences. The 20 trials with the smallest differences were defined as high difficulty; the largest 20 differences, low difficulty.

We used two analysis methods to examine the level of consistency in preference choices between the two groups. First, we calculated a between-group correlation of the proportion of subjects in each group that chose a given image in each pair, collapsing across the two difficulty levels. Second, we examined whether both groups' preference choices in the low difficulty trials agreed with the attractiveness ratings made by the pre-rating group. We limited this second analysis to low difficulty trials because only low difficulty trials had an objectively correct (i.e., higher-rated) image for the preference tasks, allowing us to define accuracy. A binary logistic regression analysis was carried for each subject and each block, regressing the dependent variable of preference decision against the consensus-preferred image as defined by the pre-rating group. This resulted in a set of beta weights representing the degree to which the higher-rated image (or rounder image in the case of the Roundness condition) predicted a subject's preference choices in a given block. We compared beta weights between groups using independent samples t-tests.

To compare our gaze results to those obtained in the original gaze cascade study (S. Shimojo et al., 2003), a similar post-experiment analysis was conducted. Eye tracking data from all trials in a condition were aligned to the time of decision (i.e., button press). For each eye-tracking point from decision time going back to 1 second before decision time, a "true" value was assigned when gaze was on the to-be-chosen stimulus, and a "false" value when gaze was on the unchosen stimulus. Points outside either stimulus were treated as "not a number." The ratio of "true" to "false" values for each time-point was averaged across trials and subjects in each group to obtain the likelihood of gaze bias toward the chosen stimulus at each time point. The data from the ASD group and from the control group were then each fit with a four-parameter sigmoid regression curve for each condition (see Figure 3.2), with the four parameters representing the following: (1) bottom plateau – baseline comparison probability between the two stimuli, (2) top plateau – gaze bias at which the participant made the conscious behavioral choice, and (3 & 4) point of inflection and slope at point of inflection – timescale indicating the quickness of the decision. Lastly, 95% confidence intervals were calculated for

the four parameter estimates. Note that because each time point is averaged over multiple trials to interpolate the sigmoid function, the fit describes the time course of gaze probability at a given time point ahead of decision time (i.e., button press) rather than trial-by-trial gaze behavior.

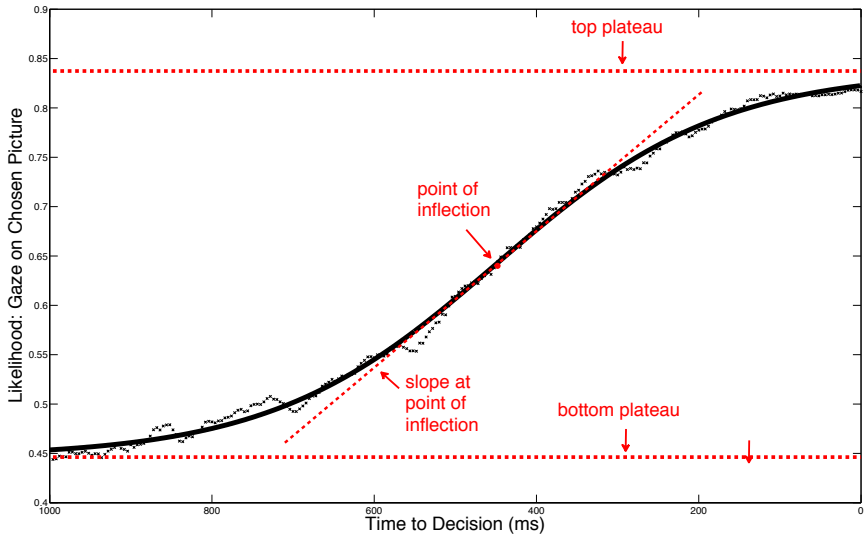


Figure 3.2. Protoypically-interpolated sigmoid with four parameters describing the time course of gaze probability at a given time point ahead of decision time (i.e., button press). Each time point of the group curve is calculated by averaging the true values across 40 trials and 12 subjects (80 trials in the Open Eyes condition). The parameters represent the following: (1) bottom plateau – baseline comparison probability between the two stimuli, (2) top plateau – gaze bias at which the participant made the conscious behavioral choice, and (3 & 4) point of inflection and slope at point of inflection – timescale indicating the quickness of the decision.

To test whether the sigmoid parameters differed significantly between groups, non-parametric permutation tests were used, with the difference between control and autism group parameter estimates as test metrics. We reshuffled the group labels (ASD, Control) to create 10,000 synthetic data sets, calculating the sigmoid fit parameters for each. The empirical distribution of the parameters was used to calculate the probability of seeing between-group parameter

differences greater than those observed in the present study. Parameter estimates were considered significantly different between groups if the difference between estimates was in the top 2.5% or bottom 2.5% of the permutation distribution for that parameter (most extreme positive or negative differences).

Reaction times (RTs) were log-transformed prior to statistical analysis to rectify the positively skewed distribution. Raw values are reported in the text and figures. Trials were excluded if reaction times were greater than 3 SD outside the group mean, or if no valid button press was registered (< 1% of the data).

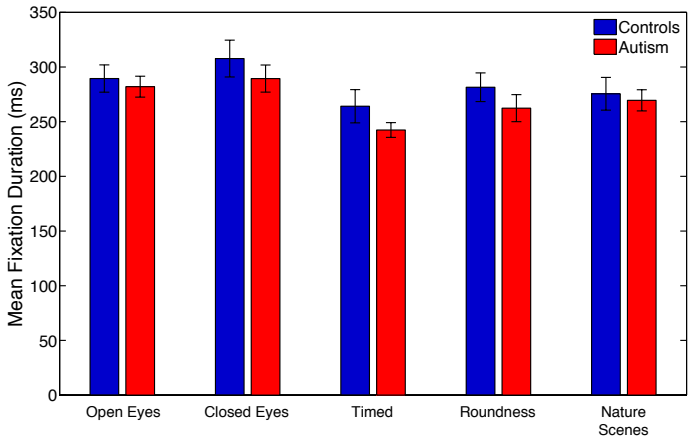
Baseline reaction times in the preliminary geometrical shape recognition task were compared between groups with a one-way ANOVA. For the five experimental conditions, RTs were first analyzed with a 2 x 5 repeated-measures ANOVA, with a between-subjects factor of group (ASD, Control) and within-subjects factor of condition (Open Eyes, Closed Eyes, Timed, Roundness, Nature Scenes). For the second level of analysis (examining the effect of decision difficulty on RTs), four (2 x 2 x 2) repeated-measures ANOVAs were carried out comparing the Open Eyes condition to each of the other four conditions, with a between-subjects factor of group and an additional two-level factor of decision difficulty (high difficulty, low difficulty). In RT analyses with decision difficulty as a factor, we analyzed all trials belonging to that difficulty level, regardless of eventual preference choice. Post-hoc tests were conducted when appropriate (2-tailed independent sample t-test, unless otherwise indicated). Degrees of freedom were Greenhouse-Geisser corrected when violations of sphericity occurred. Mean fixation durations, fixation rates, and inverse efficiency scores were each analyzed with a 2 x 5 repeated-measures ANOVA, with a between-subjects factor of group and within-subjects factor of condition.

3.2.4 Results

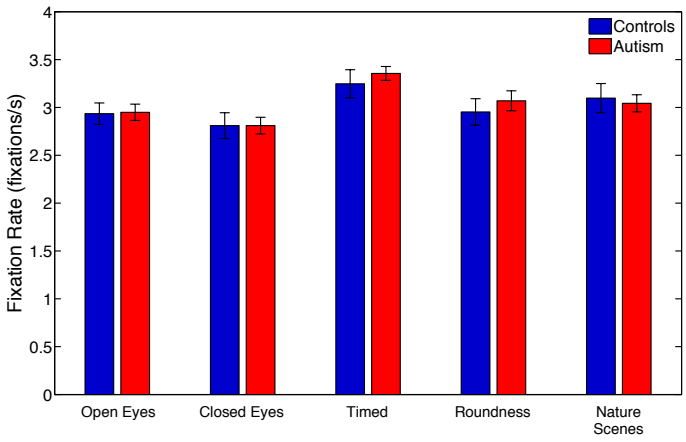
3.2.4.1 Fixation behavior

A preliminary analysis comparing mean fixation durations and fixation rates between groups revealed no significant interactions (*p*s > .663) or main effects of group (*p*s > .351). Results are summarized in Figure 3.3 below.

A



B



C

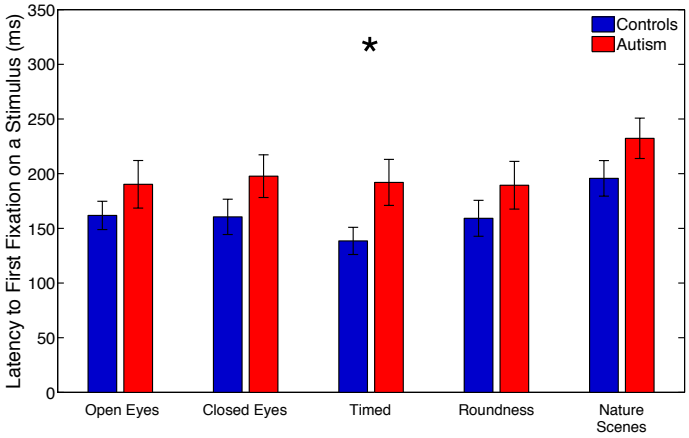


Figure 3.3. (A) Mean fixation duration (B) mean fixation rate and (C) latency to first fixation on either stimulus for the autism (red) and control (blue) groups. Error bars denote standard error. * $p < .05$, but main effect of group across conditions was not significant, $p = .132$, $\eta^2 = .10$.

3.2.4.2 Preference choices

A correlation analysis was conducted to assess the agreement between preference choices in the ASD and control groups (see Table 3.2). There was a significant positive correlation between preference choices made by the two groups in all five conditions, four of which survived correction for multiple comparisons. Attractiveness ratings for the post-rated subsets of stimuli were also strongly correlated between groups (see Table 3.3).

Table 3.2. Between-group correlation of preference choices in low and high difficulty trials combined.

	Open Eyes	Closed Eyes	Timed	Roundness	Nature Scenes
Pearson's *r*	.676 *	.445 *	.389	.830 *	.618 *
p value	< .001	.004	.012	< .001	< .001

a. *** $p < .01$ (corrected for multiple comparisons). Note that the listed significance is uncorrected.**

Table 3.3. Post-ratings of stimuli subset by control and autism participants (13-14% of all images presented in study) and between-group correlation of ratings. A subset of the images covering a range of attractiveness ratings (low, average, and high) were rated by all participants for attractiveness on a scale of 1 (very unattractive) to 7 (very attractive).

Stimulus Type		Mean Rating	*SD*	Pearson's *r*	*p* value
Female Faces					
	Control	3.27	1.02	.784*	.004
	Autism	3.35	0.59		
Male Faces					
	Control	3.23	1.16	.739*	.009
	Autism	2.81	0.45		
Desert Scenes					
	Control	4.14	1.00	.914**	< .001
	Autism	4.37	0.46		
Mountain Scenes					
	Control	4.64	1.08	.942**	< .001
	Autism	5.08	0.76		

a. *** $p < .0125$, ** $p < .0025$ (corrected for multiple comparisons). Note that the listed significance is uncorrected.**

To examine the degree to which each groups' preference choices agreed with the attractiveness ratings made by the pre-rating group, a binary logistic regression analysis was carried out for the low difficulty trials, regressing the dependent variable of preference decision against the consensus-preferred image, and t-tests were performed on the resulting beta weights (see Table 3.4). None of the group differences in beta weights were significant.

Table 3.4. Results of the binary logistic regression model for low difficulty trials, regressing the dependent variable of preference choice against the consensus-preferred image as defined by the pre-rating group (beta weight means and standard errors, and *p* values from 2-tailed t-tests).

	Open Eyes		**Closed Eyes**		**Timed**		**Roundness**		**Nature Scenes**	
	Mean β	*SE*	Mean β	*SE*	Mean β	*SE*	Mean β	*SE*	Mean β	*SE*
Control	4.09	1.69	1.40	0.29	4.81	2.38	16.32	2.89	4.15	2.43
Autism	1.89	0.31	2.83	1.81	1.19	0.32	16.20	3.06	2.97	1.86
p value	.21		.45		.15		.98		.71	

3.2.4.3 Gaze cascade effect

The likelihood that an observer's gaze was on the to-be-chosen picture was plotted against time before decision (see Figure 3.4). The results showed that the gaze cascade effect was present for both groups in all five conditions. For each group, a four-parameter sigmoid function (parameters: bottom plateau, top plateau, point of inflection, slope at point of inflection) fit the likelihood curves well in all five conditions.

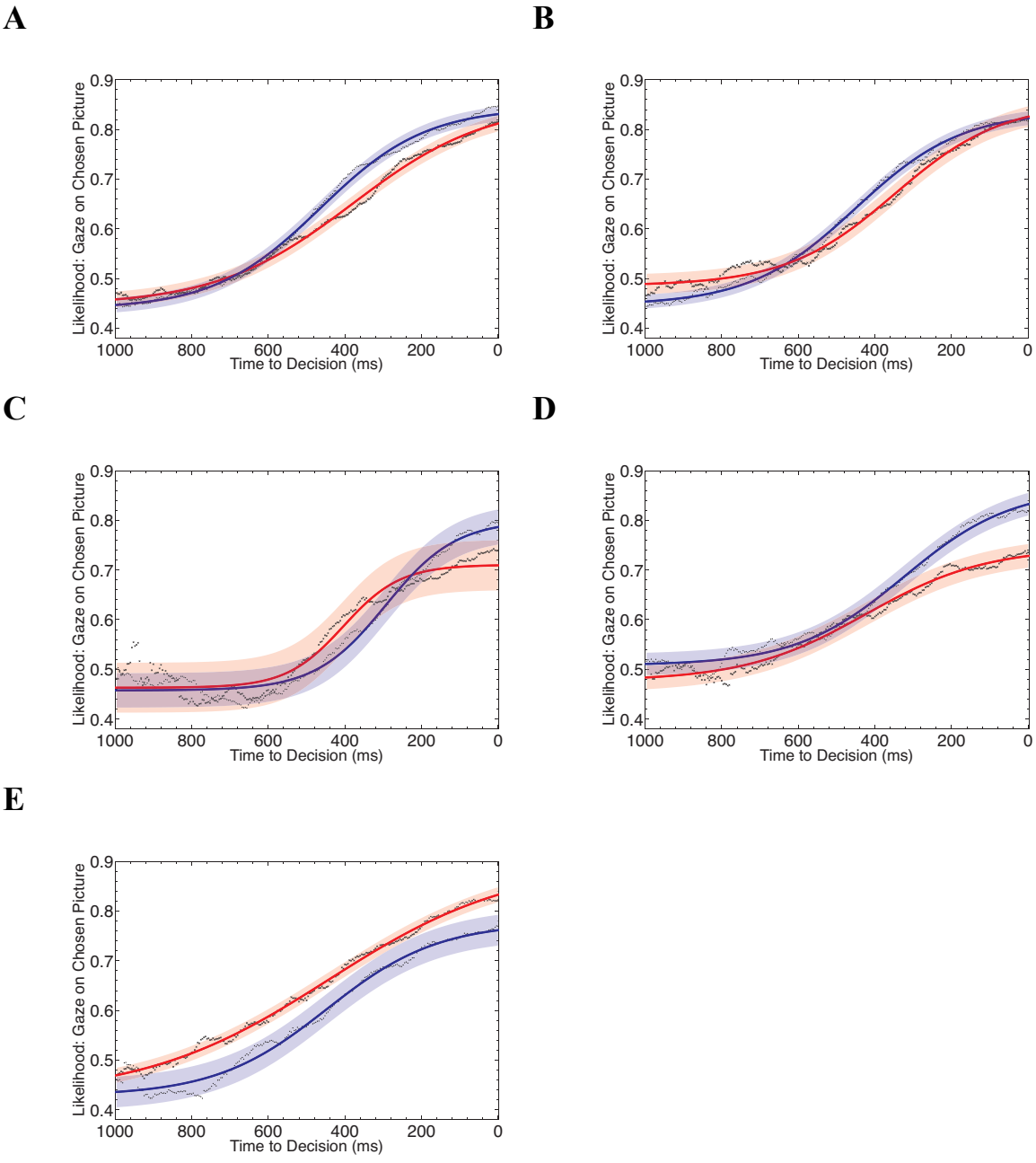


Figure 3.4. The likelihood that a participant's gaze is directed at the to-be-chosen stimulus is plotted against time to decision for the autism group (red) and control group (blue) for (A) Open Eyes, (B) Closed Eyes, (C) Timed, (D) Roundness, and (E) Nature Scenes. Dots represent raw data averaged across trials and subjects for each time point. Four-

parameter sigmoids (solid lines; Parameters: bottom plateau, top plateau, point of inflection, slope at point of inflection) were fit to each likelihood curve (all R^2s > .942). Shading denotes 95% confidence bounds of the sigmoid fit.

Based on non-parametric tests using 10,000 random group assignments, we calculated the empirical probability of seeing parameter differences greater than those observed in the present study. To test whether the sigmoid parameters differed significantly between groups, parameter estimates for the control group were subtracted from parameter estimates for the ASD group and compared against the probability distribution from permutations testing (see Methods for details). None of the parameter differences between groups in the five conditions reached $p = .05$ significance, even when a correction for multiple comparisons was not applied. Parameter estimates and results of permutation testing are summarized in Table 3.5.

Table 3.5. Permutation Analysis: Summary table of coefficient estimates for four-parameter sigmoid fits (parameters: bottom plateau, top plateau, point of inflection, slope at point of inflection), 95% confidence intervals for estimates, and probability of observed difference in parameters from random group sampling.

		Control group		Autism group		*p* (observed
Condition	Parameter	Estimate	95% CIs	Estimate	95% CIs	difference)
Open Eyes	*Bottom Plateau*	0.438	[0.435, 0.442]	0.449	[0.441, 0.450]	.44
	POI	134.0	[132.9, 135.0]	154.9	[152.8,157.1]	.29
	Slope	0.003		0.002		.89
	Top Plateau	0.845	[0.838, 0.851]	0.855	[0.841, 0.867]	.44
	R^2	0.997		0.996		
Closed Eyes	*Bottom Plateau*	0.446	[0.443, 0.449]	0.485	[0.482, 0.489]	.33
	POI	137.6	[136.5, 138.6]	162.9	[160.6,165.2]	.23
	Slope	0.003		0.003		.59
	Top Plateau	0.837	[0.831, 0.844]	0.855	[0.843, 0.867]	.41
	R^2	0.997		0.993		
Timed	*Bottom Plateau*	0.458	[0.454, 0.461]	0.463	[0.457, 0.469]	.46
	POI	176.5	[174.1, 178.9]	149.0	[146.0, 152.0]	.82
	Slope	0.004		0.003		.62
	Top Plateau	0.800	[0.786, 0.813]	0.710	[0.699, 0.721]	.91
	R^2	0.979		0.942		
Roundness	*Bottom Plateau*	0.508	[0.504, 0.512]	0.477	[0.471, 0.483]	.62
	POI	169.0	[166.2, 171.9]	144.0	[140.6, 147.4]	.68
	Slope	0.003		0.002		.80
	Top Plateau	0.865	[0.851, 0.878]	0.745	[0.731, 0.760]	.78
	R^2	0.990		0.982		
Nature Scenes	*Bottom Plateau*	0.428	[0.420, 0.436]	0.426	[0.416, 0.436]	.51
	POI	138.1	[135.3, 140.9]	139.7	[136.9,142.4]	.49
	Slope	0.002		0.002		.52
	Top Plateau	0.777	[0.762, 0.792]	0.899	[0.876, 0.922]	.14
	R^2	0.983		0.996		

3.2.4.4 Reaction times

A one-way ANOVA comparing baseline reaction time in the preliminary geometrical shape recognition task confirmed the ASD and control groups did not differ in basic motor response times, $F(1,22) = 0.02$, $p = .882$.

Reaction times for the experimental conditions were first analyzed using a 2 x 5 ANOVA comparing all five experimental conditions (see Figure 3.5). Compared to controls, the ASD group had faster reaction times overall, reflected in a near-significant main effect of group, $F(1,22) = 4.23$, $p = .052$, $\eta^2 = .16$. Post-hoc comparisons revealed significant group differences in the Closed Eyes condition (ASD: $M = 2.16$, $SE = 0.32$; Controls: $M = 3.13$, $SE = 0.30$), $t(22) = -2.31$, $p = .030$, and Timed condition (ASD: $M = 1.22$, $SE = 0.14$; Controls: $M = 1.62$, $SE = 0.14$), $t(22) = -2.13$, $p = .045$, and a trend-level group difference in the Open Eyes condition (ASD: $M = 2.04$, $SE = 0.20$; Controls: $M = 2.77$, $SE = 0.27$), $t(22) = -1.93$, $p = .067$. Differences in RTs in the Roundness and Nature Scenes conditions were not significant ($p = .179$ and $p = .400$, respectively).

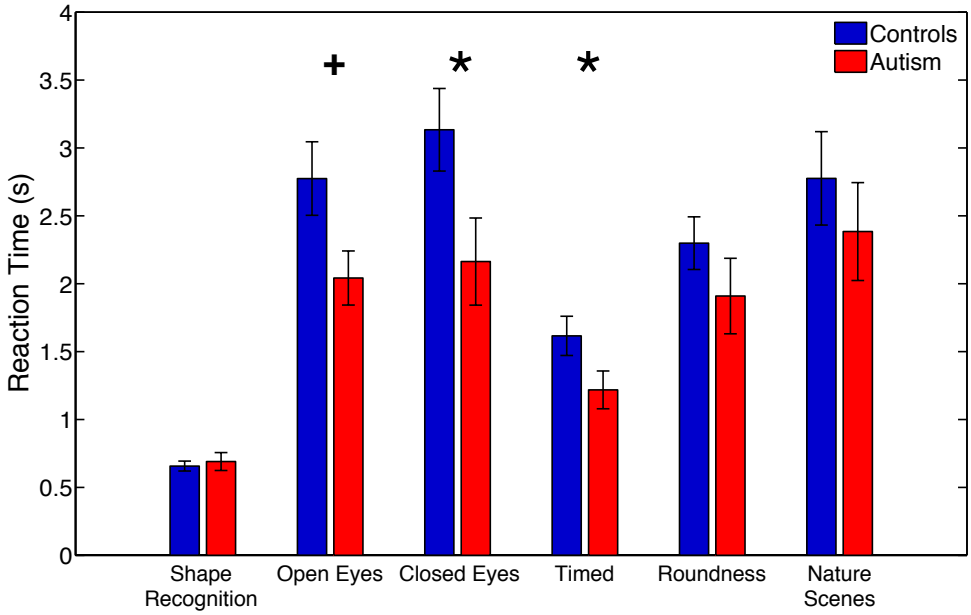


Figure 3.5. Mean reaction times for the preliminary geometrical shape recognition task and experimental conditions, for the autism (red) and control (blue) groups. Error bars denote standard error. * $p < .05$, + $p < .10$.

To investigate RT differences between groups in the Open Eyes condition in comparison to the other conditions, a (2 x 2 x 2) repeated-measures ANOVA (factors: group x condition x difficulty) was calculated each time comparing the Open Eyes condition to each of the other

four experimental conditions, with a between-subjects factor of group (ASD, Control) and a two-level factor of decision difficulty (high difficulty, low difficulty). Means and standard errors for RTs in the individual conditions are shown in Table 3.6.

Face Preference: Open Eyes vs. Closed Eyes

The ANOVA comparing the effect of Closed Eyes versus Open Eyes on RTs indicated there was a significant main effect of group, $F(1,22) = 4.93$, $p = .037$, $\eta^2 = .183$, for faster RTs in the ASD group compared to the control group. None of the other main effects or interactions reached significance (all *p*s > .146).

Face Preference: Timed vs. Untimed

The ANOVA comparing the Timed condition to the self-paced Open Eyes condition revealed a significant interaction between group and difficulty on RTs, $F(1,22) = 6.12$, $p = .022$, $\eta^2 = .218$, as well as a trend-level three-way interaction, $F(1,22) = 3.69$, $p = .068$, $\eta^2 = .144$. Paired-samples t-tests indicated trend-level differences in the Timed condition for controls (Controls: High difficulty: $M = 1.63$, $SE = 0.14$; Low difficulty: $M = 1.60$, $SE = 0.15$), $t(11) = -1.75$, $p = .109$, but not for the ASD group (ASD: High difficulty: $M = 1.23$, $SE = 0.14$; Low difficulty: $M = 1.21$, $SE = 0.14$), $t(11) = -0.73$, $p = .484$. There was also a significant group effect for faster RTs in the ASD group compared to controls, $F(1,22) = 6.59$, $p = .018$, $\eta^2 = .230$.

Face Preference vs. Face Roundness

The ANOVA comparing the Roundness condition to Open Eyes revealed a significant interaction between condition and difficulty on RTs, $F(1,22) = 15.56$, $p = .001$, $\eta^2 = .414$, as well as a trend-level group effect, $F(1,22) = 2.99$, $p = .098$, $\eta^2 = .120$. Paired-samples t-tests indicated both groups took significantly longer for high difficulty compared to low difficulty decisions in the Roundness task (Controls: High difficulty: M = 2.58, SE = 0.24; Low difficulty: M = 2.01, SE = 0.18), t(11) = -3.41, p = .006, (ASD: High difficulty: M = 2.08, SE = 0.32; Low difficulty: M = 1.74, SE = 0.25), t(11) = -2.66, p = .022.

Social vs. Non-social Preference

The ANOVA comparing the Nature Scenes condition to Open Eyes revealed a significant interaction between group and difficulty, $F(1,22) = 7.01$, $p = .015$, $\eta^2 = .242$, indicating that

decision difficulty had a different effect on RTs in the control group than on those in the ASD group. There was also a main effect of difficulty, $F(1,22) = 4.53$, $p = .045$, $\eta^2 = .171$. None of the other main effects or interactions reached significance (all ps > .177).

To examine the effect of decision difficulty on RTs in each group, within-group comparisons were performed on pooled data from the Nature Scenes and Open Eyes conditions. Paired-samples t-tests showed the control group took longer to make decisions in high difficulty trials compared to low difficulty trials (High difficulty: $M = 2.85$, $SE = 0.29$; Low difficulty: $M = 2.70$, $SE = 0.27$), $t(11) = -2.97$, $p = .013$, whereas there was not a significant effect of difficulty on RTs in the ASD group (High difficulty: $M = 2.21$, $SE = 0.26$; Low difficulty: $M = 2.22$, $SE = 0.26$), $t(11) = 0.32$, $p = .757$.

Inverse Efficiency Scores

Lastly, we checked for a speed-accuracy tradeoff by analyzing RT and accuracy together, computing inverse efficiency scores (i.e., reaction time divided by accuracy) for each participant and condition in the low difficulty trials. A 2 x 5 ANOVA with a between-subjects factor of group and within-subjects factor of condition indicated there was no interaction between condition and group ($p = .805$) and no significant difference between groups ($p = .108$).

Correlation with AQ

There were no significant correlations between Autism Quotient scores (AQ) and RTs for the ASD group, nor IQ and RTs for either group.

Table 3.6. Mean reaction times in seconds (non-transformed values) and standard errors for high and low difficulty trials, and mean accuracy scores for low difficulty trials.

		Control group				Autism group			
		Reaction Time		Accuracy		Reaction Time		Accuracy	
Condition		*Mean*	*SE*	*Mean*	*SE*	*Mean*	*SE*	*Mean*	*SE*
Shape Recognition		0.66	0.04	99.6%	0.00	0.69	0.07	100%	0.00
	Difficulty Level								
Open Eyes									
	High	2.89	0.30	-	-	2.01	0.19	-	-
	Low	2.66	0.25	75.8%	0.03	2.07	0.21	70.4 %	0.03
Closed Eyes									
	High	3.20	0.35	-	-	2.18	0.33	-	-
	Low	3.07	0.27	65.1%	0.03	2.15	0.32	62.8%	0.04
Timed									
	High	1.63	0.14	-	-	1.23	0.14	-	-
	Low	1.60	0.15	59.6%	0.03	1.21	0.14	55.7%	0.03
Roundness									
	High	2.58	0.24	-	-	2.08	0.32	-	-
	Low	2.01	0.18	89.6%	0.06	1.74	0.25	92.5%	0.02
Nature Scenes									
	High	2.81	0.32	-	-	2.41	0.37	-	-
	Low	2.73	0.37	61.7%	0.04	2.36	0.35	65.4%	0.05

3.2.5 Discussion

Here, we found that individuals with ASD and controls made similar preference decisions in judging the attractiveness of faces, and that they arrived at those decisions using similar sampling processes, displaying the "gaze cascade" interaction between internal preference and attention bias. Where the ASD group differed from controls was in faster decision times, and also in an insensitivity to task difficulty in the facial preference tasks. Whereas reaction times generally increased for difficult judgments in controls, the ASD group responded equally quickly when judging the attractiveness of closely-matched faces.

People with ASD made similar preference choices compared to the control group. Preference choices were correlated between the two groups, and the ASD group chose the higher-rated image with generally the same frequency as controls across all conditions. Additionally, attractiveness ratings for the post-rated subset of stimuli were strongly correlated between groups (see Table 3.3), which strongly suggests the initial ratings used to define difficulty level are also appropriate for the ASD group. In other words, face pairs that were defined as equally-attractive face pairs based on non-autistic pre-ratings were also likely to be considered equally attractive by ASD subjects.

With respect to visual behavior, when we examined mean fixation durations and mean fixation rates, no significant group differences were detected in the details of the gaze pattern. Moreover, both the ASD and control groups replicated the gaze cascade effect observed in the original paper (S. Shimojo et al., 2003). That is, the feedback loop linking visual orienting with preference decisions is intact in ASD, which was not expected given the literature on atypical gaze to faces in autism. This indicates that the ASD group used similar preference decision-making processes compared to neurotypicals even with social stimuli. Lastly, comparison of the four parameters of the gaze cascade curves using permutations testing revealed no significant differences between the groups in any of the conditions. Thus, the process of visual orienting to the preferred stimulus and the temporal profile of fixations leading up to the choice exists in the ASD group independent of stimulus and decision type.

Despite the lack of differences in decision outcomes and orienting behavior, the ASD group was significantly faster in making preference decisions overall. This effect may seem incompatible with the lack of difference in gaze cascade fits, but the gaze cascade model is time-locked to the final response (decision), not the onset of the stimulus, and thus the model is relatively insensitive to variances in total performance time (RT), as well as the initial response (gaze) to the stimulus. The source of the speeded responses is unclear, but the data do contain some suggestive clues. First, the lack of significant group differences in the gaze cascade model fits strongly suggests that the processing advantage is not due to an abbreviated or otherwise abnormal feedback loop linking foveation and eventual preference. Second, post-hoc tests indicated that the main reaction time advantage stemmed mainly from faster response times in

preference decisions for faces, as opposed to the objective face decisions or the decisions for natural scenes, and that there was a complete lack of a reaction time advantage in the geometrical shape discrimination. This suggests that the mechanism lies in a higher-level component of preferential decision-making for faces, rather than in low-level motor, visual, or executive factors.

Our other analyses of fixation behavior did not point to a particular source of the speeded responses. However, we did find an isolated effect of shorter latencies to first face fixation in the Timed condition for ASD (see Figure 3.3-C). A future study focusing on this high-pressure condition may be able to uncover more informative results regarding the early phases of preference formation.

Given the faster reaction times in ASD, we also examined whether the difficulty of the decision affects reaction times. Interestingly, the ASD group was insensitive to the difficulty of the decision, whereas controls had slower reaction times when images were similarly rated, as expected. Most intriguingly, this insensitivity was strongest for face preference decisions: difficulty did increase RTs for face roundness judgments in ASD. Our failure to find any robust RT differences in the nature scenes condition may have been due to lack of statistical power. It is worth noting that even in controls there was not a strong effect of difficulty for nature scenes. Thus, RTs in the ASD group seem to be particularly insensitive to decision difficulty for social preference decisions.

We found no evidence to indicate the faster RTs were due to inattention or a random or rushed decision-making process. The ASD group's preferences were not divergent from or noisier than the control group's preferences. The strong correlation of the ASD group's choices with both the control group's choices and the attractiveness pre-ratings from a separate non-autistic group indicates the ASD group used similar or convergent criteria to evaluate attractiveness. Finally, the lack of a group difference in inverse efficiency scores reflects that faster RTs were not accompanied by a disproportionately large decrease in accuracy in ASD (i.e., there was not a corresponding loss in performance). Thus, one possible explanation could be that a choice criterion is reached in social decisions regardless of the discriminability of the options, although

the fundamental mechanism underlying the choice decision may be shared between groups. Future studies with more formal modeling approaches than the methods used here would be needed to test this hypothesis.

There is precedent for the idea that people with ASD may be faster on certain kinds of timed visual/perceptual tasks. A study by Hayashi and colleagues reported that children with Asperger's Syndrome scored higher than typically developing children on the Raven's Standard Progressive Matrices test (RSPM) (Hayashi, Kato, Igarashi, & Kashima, 2008), a nonverbal intelligence test in which subjects identify the missing geometric element that completes a specific pattern. Another study using the RSPM found that while people with autism performed the test with the same accuracy as controls (Soulières et al., 2009), their response times were significantly faster, suggesting that in certain situations visual processing was enhanced in ASD. There is also evidence to indicate people with ASD can outperform neurotypicals in tasks involving mental rotation (Soulières, Zeffiro, Girard, & Mottron, 2011), visual search (Jolliffe & Baron-Cohen, 1997; Keehn et al., 2008) and visual discrimination (Joseph, Keehn, Connolly, Wolfe, & Horowitz, 2009). The explanations given for such results include an underlying local processing advantage, lack of engagement with stimuli allowing for more efficient processing, or perhaps fundamental differences in motivational state.

One contrast between the above results and our results is that our task is ostensibly social in nature, a domain in which people with ASD are generally thought to be at a disadvantage. There are a few related factors that could help to interpret this discrepancy. First, it is known that individuals with autism can mitigate social deficits using explicitly and implicitly guided compensatory strategies, masking social impairments in spite of atypical processing of social stimuli. The effectiveness of such explicit top-down strategies has been found in tasks involving facial discrimination and emotion recognition (Rutherford & McIntosh, 2006; Teunisse & de Gelder, 2001; Wong et al., 2008). Similarly, implicit compensatory strategies, such as prioritizing of local over configural information (Dawson et al., 2005; Rondan & Deruelle, 2007) are reported to underlie the performance advantage observed in ASD relative to controls in certain types of face perception tasks (Hobson et al., 1988; Langdell, 1978; Tantam et al., 1989). Second, it may be that the face preference task does not involve higher-

level social judgments. The task regarded personal preferences, and did not require mental state inferences or social attributions regarding the face or other potential viewers, domains in which high-functioning individuals are more likely to show impairments compared to lower-level social processes that are often spared. In that sense, the task might even have been approached as a perceptual task, rather than a social one. This would be consistent with the faster RTs observed in ASD, and also the insensitivity of RTs to the relative attractiveness of the faces. Finally, it could be the case that face processing deficits in high-functioning ASD become apparent only when there are more complex attentional demands, such as in real-life situations, or when there is competing visual information, such as with dynamic stimuli. This could also occur if attentional demands become too great to sustain explicit or implicit compensatory strategies.

The current study had several limitations. First, while the use of computer-generated faces is favorable in terms of controlling for potential confounds (e.g., facial expression), social stimuli with greater ecological validity (such as photographs or dynamic stimuli) may be more likely to elicit atypical gaze behavior, particularly in individuals with high-functioning autism. Second, the difficulty factor was predefined based on ratings obtained from a separate group of non-autistic participants. Due to time limitations during the actual experiment, we obtained post-ratings for only a small portion of the stimuli that were used. While we chose images that reflected a range of attractiveness ratings, people with ASD may have different face preferences that were not captured by the stimuli presented in the post-rating set. Future directions include gathering ratings for all stimuli to be presented in the study and using these ratings to determine face pairings separately for each group, in order to eliminate the possibility that the two groups perceived task difficulty differently.

In summary, individuals with high-functioning autism have a similar gaze cascade and also made similar preference choices across the stimuli compared to neurotypicals. We can therefore conclude that in individuals with high-functioning autism, the preference formation mechanism linking gaze orienting and eventual choice is intact. With these similarities in mind, however, there were two major differences between groups: reaction times in the autism group were faster compared to controls, and furthermore they were insensitive to the difficulty

of the choice. Thus, more detailed analysis of task difficulty, reaction times, and even face preferences would help here, and in the future, to determine whether subjective decisions about faces systematically differ in people with ASD. It may be worth especially paying attention to the initial phase of orienting and perceptual processing leading up to the preference decision, as discussed above. In future work, researchers might investigate the extent to which deficits in processing social information affect preference decisions using dynamic or emotional stimuli.

3.3 Gaze Cascade Study in Amygdala Lesion Patients

Here, we tested three patients with rare amygdala lesions to examine whether social processing impairments would affect preference decisions for faces and the temporal evolution of those decisions. Due to the small sample size, group comparisons lacked the statistical power to allow us to draw quantitative conclusions. Considering, however, the rarity of testing amygdala lesion patients, we decided to report the results here and discuss qualitative trends in the data worthy of future investigation.

3.3.1 Materials and methods

3.3.1.1 Participants

AP, AM, and BG are three female participants with bilateral amygdala lesions caused by Urbach-Wiethe disease (M_{age} = 34.3 years, *SD* = 6.4, age range = 27-38). Two of the participants, AM and BG, are monozygotic twins. The anatomical scans of the lesions for the three participants are shown below in Figure 3.6.

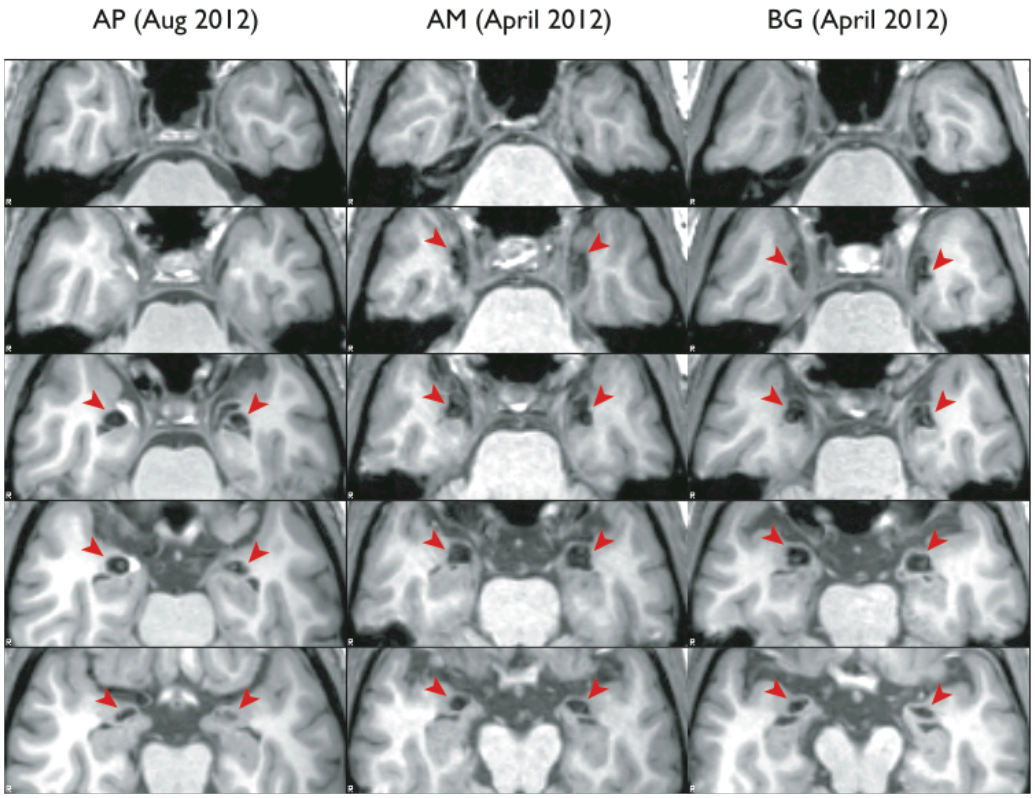


Figure 3.6. Anatomical scans of the amygdala lesion patients. Red arrows indicate location of the amygdala calcification damage. (Source: Mike Tyszka, Caltech Brain Imaging Center).

The comparison group consisted of 3 healthy female controls (M_{age} = 34.0 years, *SD* =4.6, age range = 29-38), group-matched for age and IQ (as measured by the Wechsler Abbreviated Scale of Intelligence; (Wechsler, 1999), with no family history of psychiatric illness. Table 3.7 summarizes demographic and diagnostic information for participants.

Independent samples t-tests showed that the groups did not significantly differ in terms of age, $t(4) = 0.07$, $p = .945$) and IQ ($t(4) = -2.30$, $p = .083$. All participants gave written informed consent to participate under a protocol approved by the Institutional Review Board of the California Institute of Technology.

Table 3.7. Demographic information for amygdala lesion and control participants in the gaze cascade study.

Amygdala participants				
	Age	*Verbal IQ*	*Full scale IQ*	*AQ*
AP	27	92	98	20
AM	38	94	96	21
BG	38	99	101	18
Mean	34.3	95.0	98.3	
SD	6.4	3.6	2.5	
Control participants				
	Age	*Verbal IQ*	*Full scale IQ*	*AQ*
1	35	108	107	-
2	29	116	116	9
3	38	104	102	11
Mean	34.0	109.3	108.3	
SD	4.6	6.1	7.1	

a. Verbal IQ and full-scale IQ from the Wechsler Abbreviated Scale of Intelligence; AQ: Autism Quotient.

3.3.1.2 Stimuli and apparatus

Stimuli were identical to the stimuli described in the Methods section of the Gaze Cascade study in autism participants (for details, see section 3.2.3.2 Stimuli and apparatus). Stimuli consisted of either pairs of social stimuli (computer-generated human faces) or pairs of non-social stimuli (nature scenes sourced from a google image search for "desert" and "mountain"). Face images, generated using Facegen (Singular Inversions, Vancouver, Canada), were front-facing with neutral emotional expression and direct eye contact. Stimuli were paired using the same procedures outlined in the previous study with autism participants.

Images were presented on a 23" TFT monitor with a pixel resolution of 1920 x 1080. The stimuli in each test pair were presented simultaneously on the left and right side of the screen. At a viewing distance of approximately 62 cm, each stimulus pair had an overall size of 36.5 (width) x 14.4 (height) degrees of visual angle.

A desk-mounted Tobii TX300 eye tracker (Tobii Technology, Falls Church, VA, USA) was used to collect gaze data. Stimuli were presented using Matlab (Mathworks, Natick, MA) and the Psychophysics toolbox (Brainard, 1997), and the T2T-Talk2Tobii toolbox (Deligianni, Senju, Gergely, & Csibra, 2011). Corneal and pupil reflection were recorded at a sampling rate of 300 Hz. At the beginning of each block, a 9-point calibration was performed. Each trial began by requiring subjects to fixate on a central drift correction dot. After the eye-tracker registered a successful fixation, participants pressed the space bar to start the trial.

3.3.1.3 Procedure

Experiment procedure was identical to the procedure described in the Methods section of the Gaze Cascade study in autism participants (for details, see section 3.2.3.3 Procedure). Subjects performed various 2-alternative forced-choice (2AFC) tasks while eye-gaze was tracked (see Figure 3.7 for summary of experimental conditions and example stimuli). The same conditions were tested as in the study with autism participants, with the exception of Faces with Closed Eyes, which we omitted here. Each amygdala participant was tested twice on two different days to increase the likelihood of collecting reliable data.

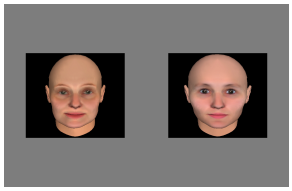
Condition Name	Stimuli Description	Example Stimuli	Time per Trial	Decision Type
Open Eyes	Faces with Open Eyes		Self-paced (2 x 40 trials)	Preference Judgment
Timed	Faces with Open Eyes		**1.5 seconds** (40 trials)	Preference Judgment
Roundness	Faces with Open Eyes		Self-paced (40 trials)	**Objective Judgment**
Nature Scenes	**Nature Scenes**		Self-paced (40 trials)	Preference Judgment

Figure 3.7. Summary of experimental conditions and example stimuli.

3.3.1.4 Analyses

Analyses were identical to the analyses described in the Methods section of the Gaze Cascade study in autism participants (see section 3.2.3.4 Analyses), unless noted here. The general methods of the analyses are described below again for convenience, but for further detail, please refer to Chapter 3.2.

Data from the amygdala group and from the control group were each fit with a four-parameter sigmoid regression curve for each condition, with four parameters representing the following: (1) bottom plateau – baseline comparison probability between the two stimuli, (2) top plateau – gaze bias at which the participant made the conscious behavioral choice, and (3

& 4) point of inflection and slope at point of inflection – timescale indicating the quickness of the decision. Finally, 95% confidence intervals were calculated for each of the four parameters estimated.

Due to the small sample size in this study, the permutations test that was performed in the ASD subjects was determined to lack power and therefore was not performed. For the comparisons presented here, differences between groups were considered significant when confidence intervals did not overlap.

Analysis of accuracy was limited to low difficulty trials because only low difficulty trials had an objectively correct (i.e., higher-rated) image for the preference tasks, allowing us to define accuracy.

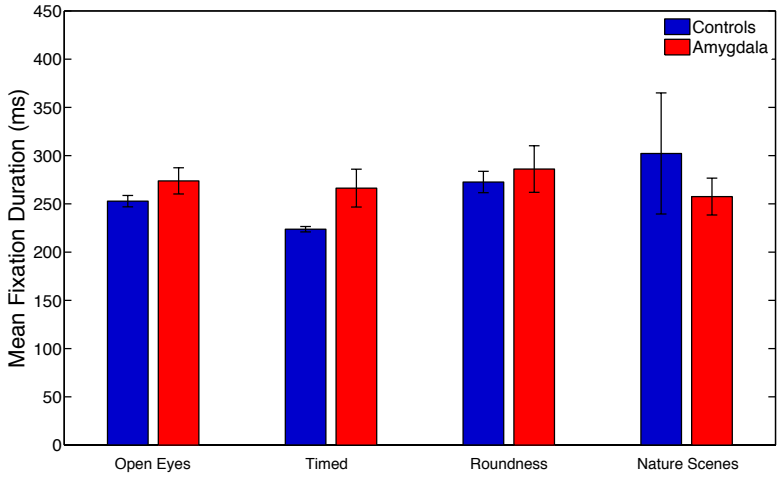
Since the distributions for reaction times (RT) were positively skewed, log-transformations were conducted prior to statistical analysis. Raw values are reported in the text and figures. Trials were excluded if reaction times were greater than 3 SD outside the group mean, if no valid button press was registered, or if more than 20% of the eyetracking data was invalid (< 4% of the data).

3.3.2 Results

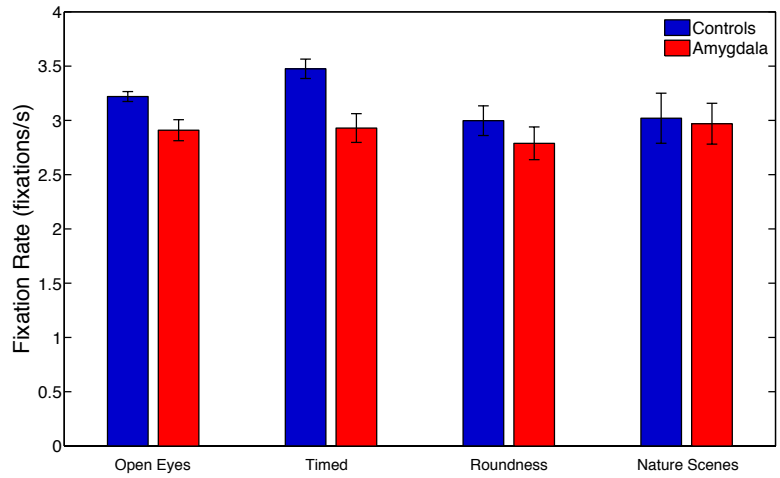
3.3.2.1 Fixation behavior

A preliminary analysis between groups comparing mean fixation durations, fixation rates, and latency to first fixation on an image revealed no significant interactions (ps > .292) or main effects of group (ps > .110). Results are summarized in Figure 3.8.

A


Controls
Amygdala
Mean Fixation Duration (ms)
450
400
350
300
250
200
150
100
50
0
Open Eyes
Timed
Roundness
Nature Scenes

B


Controls
Amygdala
Fixation Rate (fixations/s)
4
3.5
3
2.5
2
1.5
1
0.5
0
Open Eyes
Timed
Roundness
Nature Scenes

C

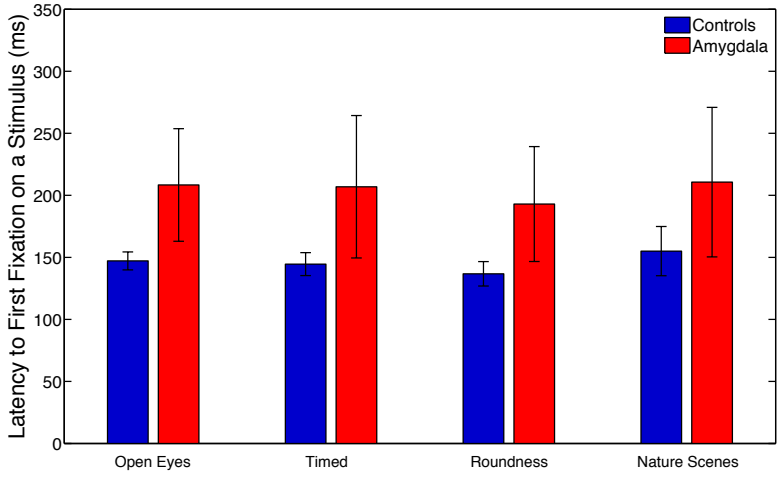

Controls
Amygdala
Latency to First Fixation on a Stimulus (ms)
350
300
250
200
150
100
50
0
Open Eyes
Timed
Roundness
Nature Scenes

Figure 3.8. Mean fixation duration (A) mean fixation rate (B) and latency to first fixate on an image (C) for the amygdala (red) and control (blue) groups. Error bars denote standard error.

3.3.2.2 Preference choices

A correlation analysis was conducted to assess the agreement between preference choices in the amygdala and control groups (see Table 3.8). There was a weak correlation in the Open Eyes condition and a moderate correlation in the Roundness condition. Only the latter result survived correction for multiple comparisons.

Table 3.8. Between-group correlation of preference choices in low and high difficulty trials combined.

	Open Eyes	Timed	Roundness	Nature Scenes
Pearson's *r*	.355	.253	.505 *	-.172
p value	.024	.115	< .001	.288

a. * $p < .01$ (corrected for multiple comparisons). Note that the listed significance is uncorrected.

To examine the degree to which each groups' preference choices agreed with the attractiveness ratings made by the pre-rating group, a binary logistic regression analysis was carried out for the low difficulty trials, regressing the dependent variable of preference decision against the consensus-preferred image, and t-tests were performed on the resulting beta weights (see Table 3.9). None of the group differences in beta weights were significant.

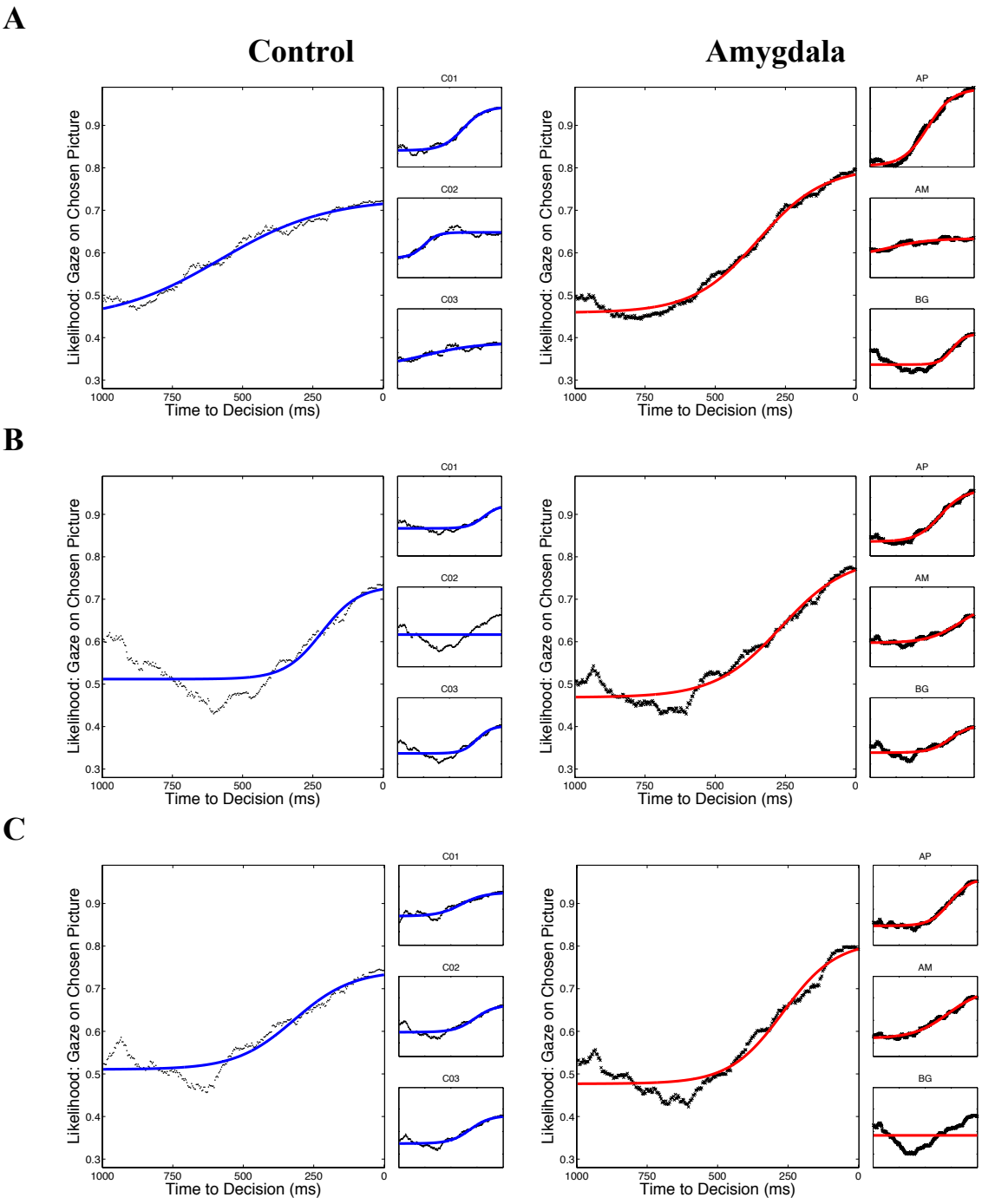
Table 3.9. Results of the binary logistic regression model for low difficulty trials, regressing the dependent variable of preference choice against the consensus-preferred image as defined by the pre-rating group (beta weight means and standard errors, and *p* values from 2-tailed t-tests).

	Open Eyes		**Timed**		**Roundness**		**Nature Scenes**	
	Mean β	*SE*	Mean β	*SE*	Mean β	*SE*	Mean β	*SE*
Control	0.56	0.45	1.08	0.43	0.50	0.87	1.70	0.47
Amygdala	1.26	0.51	1.48	0.37	0.33	0.06	1.69	1.00
p value	.36		.52		.86		.99	

3.3.2.3 Gaze cascade effect

Individual subject curves

The likelihood that an observer's gaze was on the to-be-chosen picture was plotted against time before decision (see Figure 3.9). Analysis of individual subjects' likelihood curves indicated that the gaze cascade effect was present for each individual subject in all conditions.


A
Control
Amygdala
B
C
Likelihood: Gaze on Chosen Picture
Time to Decision (ms)
C01
C02
C03
AP
AM
BG

D

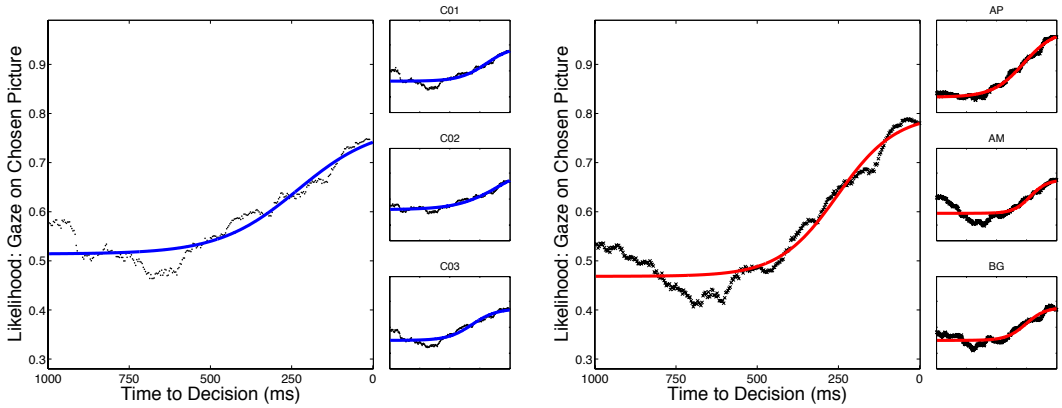


Figure 3.9. Sigmoid fits for individual control subjects (blue) and amygdala lesion subjects (red) for (A) Open Eyes, (B) Timed, (C) Roundness, and (D) Nature Scenes. Large figures depict group averages, small figures depict individual subject fits. Dots represent raw data averaged across trials and subjects for each time point.

Group curves

The results showed that the gaze cascade effect was present for both groups in all four conditions (see Figure 3.10). In the Open Eyes condition, the time course of the gaze cascade was shorter and reached a higher plateau in the amygdala group compared to the control group, as indicated by the lack of overlap of 95% confidence bounds at the points of inflections and peaks.

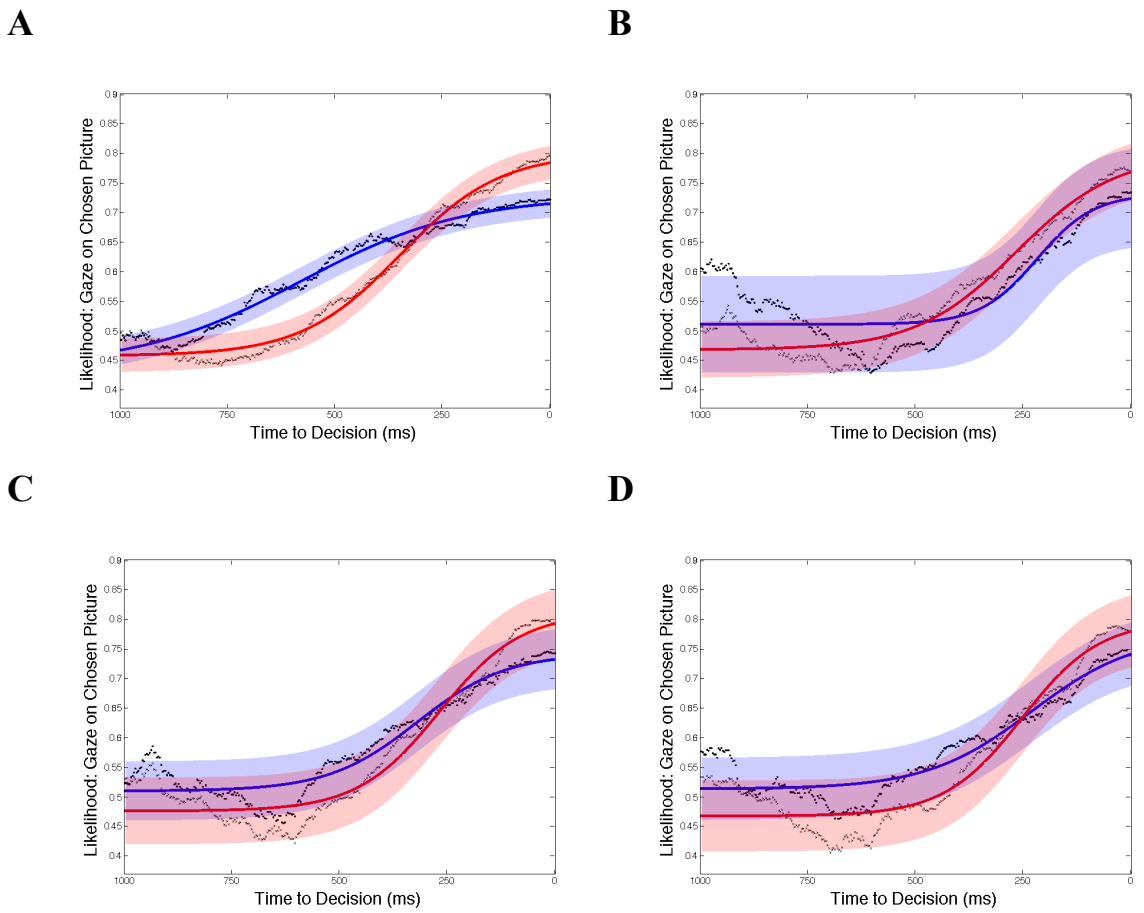


Figure 3.10. The likelihood that a participant's gaze is directed at the to-be-chosen stimulus is plotted against time to decision for the amygdala lesion group (red) and control group (blue) for (A) Open Eyes, (B) Timed, (C) Roundness, and (D) Nature Scenes. Dots represent raw data averaged across trials and subjects for each time point. Four-parameter sigmoids (solid lines; Parameters: bottom plateau, top plateau, point of inflection, slope at point of inflection) were fit to each likelihood curve (all R^2s > .757). Shading denotes 95% confidence bounds of the sigmoid fit.

For each group, a four-parameter sigmoid function (parameters: bottom plateau, top plateau, point of inflection, slope at point of inflection) fit the likelihood curves well in all four

conditions. Coefficient parameters for the sigmoid fits and 95% confidence intervals for parameter estimates are summarized in Table 3.10.

Table 3.10. Summary table of coefficient estimates for four-parameter sigmoid fits (parameters: bottom plateau, top plateau, point of inflection, slope at point of inflection), and 95% confidence intervals for estimates.

		Control group		Amygdala group	
Condition	Parameter	Estimate	95% CIs	Estimate	95% CIs
Open Eyes	*Bottom Plateau*	0.440	[0.426, 0.453]	0.459	[0.455, 0.462]
	POI	125.8	[120.7, 130.9]	195.8	[193.2,198.3]
	Slope	0.001		0.002	
	Top Plateau	0.728	[0.709, 0.748]	0.801	[0.789, 0.811]
	R^2	0.980		0.986	
Timed	*Bottom Plateau*	0.519	[0.505, 0.518]	0.469	[0.463, 0.474]
	POI	234.5	[226.6, 242.5]	220.2	[213.7, 226.6]
	Slope	0.003		0.002	
	Top Plateau	0.732	[0.702, 0.761]	0.799	[0.772, 0.826]
	R^2	0.757		0.949	
Roundness	*Bottom Plateau*	0.511	[0.505, 0.516]	0.477	[0.471, 0.482]
	POI	204.1	[197.9, 210.3]	219.6	[214.4, 224.7]
	Slope	0.002		0.003	
	Top Plateau	0.743	[0.724, 0.761]	0.812	[0.788, 0.835]
	R^2	0.912		0.939	
Nature Scenes	*Bottom Plateau*	0.514	[0.508, 0.520]	0.468	[0.463, 0.474]
	POI	230.8	[218.6, 242.9]	224.2	[218.7,229.7]
	Slope	0.002		0.003	
	Top Plateau	0.776	[0.736, 0.815]	0.800	[0.773, 0.824]
	R^2	0.889		0.928	

3.3.2.4 Reaction times

A one-way ANOVA comparing baseline reaction times in the preliminary geometrical shape recognition task confirmed the amygdala and control groups did not differ in basic motor response times, $F(1,4) = 0.26$, $p = .640$.

Reaction times for the experimental conditions were first analyzed using a 2 x 4 ANOVA, comparing all four experimental conditions (see Figure 3.11). There was no group difference in RTs ($p = .838$, $\eta^2 = .01$) and no interaction between group and condition ($p = .225$, $\eta^2 = .29$).

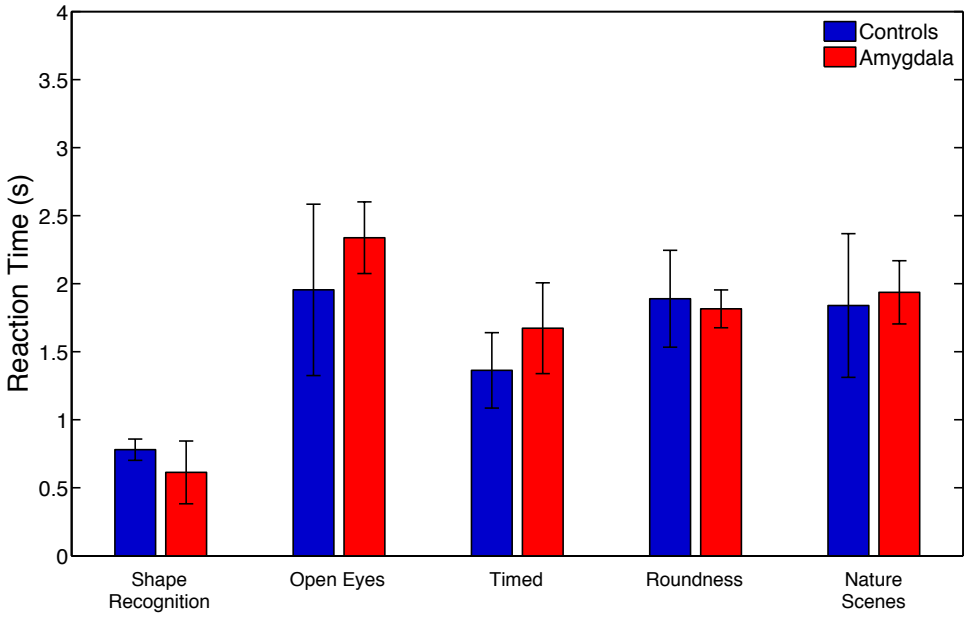


Figure 3.11. Mean reaction times for the preliminary geometrical shape recognition task and experimental conditions, for the amygdala (red) and control (blue) groups. Error bars denote standard error.

To investigate RT differences between groups in the Open Eyes condition in comparison to the other conditions, a (2 x 2 x 2) repeated-measures ANOVA (factors: group x condition x difficulty) was calculated each time comparing the Open Eyes condition to each of the other three experimental conditions, with a between-subjects factor of group (Amygdala, Control)

and a two-level factor of decision difficulty (high difficulty, low difficulty). Means and standard errors for RTs in the individual conditions are shown in Table 3.11.

Table 3.11. Mean reaction times in seconds (non-transformed values) and standard errors for high and low difficulty trials, and mean accuracy scores for the low difficulty trials.

		Control group				Amygdala group			
		Reaction Time		Accuracy		Reaction Time		Accuracy	
Condition		*Mean*	*SE*	*Mean*	*SE*	*Mean*	*SE*	*Mean*	*SE*
Shape Recognition		0.78	0.23	100%	0.00	0.61	0.08	100%	0.00
	Difficulty Level								
Open Eyes									
	High	1.94	0.26	-	-	2.38	0.70	-	-
	Low	1.97	0.26	57.5%	0.05	2.29	0.59	63.8 %	0.05
Timed									
	High	1.33	0.32	-	-	1.62	0.23	-	-
	Low	1.40	0.34	61.7%	0.04	1.73	0.35	60.0%	0.03
Roundness									
	High	1.96	0.14	-	-	2.13	0.41	-	-
	Low	1.82	0.19	83.3%	0.07	1.50	0.30	96.7%	0.01
Nature Scenes									
	High	1.87	0.24	-	-	1.97	0.53	-	-
	Low	1.81	0.22	71.3%	0.06	1.90	0.52	68.3%	0.10

Face Preference: Timed vs. Untimed

The ANOVA comparing the Timed condition to the self-paced Open Eyes condition revealed no significant interaction effects nor a main effect of group (all *p*s > .283).

Face Preference vs. Face Roundness

The ANOVA comparing the Roundness condition to Open Eyes revealed a significant interaction between group and difficulty, $F(1,4) = 11.92$, $p = .026$, $\eta^2 = .749$, indicating that decision difficulty had a different effect on RTs in the control group than on those in the

amygdala group. There was also an interaction between condition and difficulty, $F(1,4) = 12.46$, $p = .024$, $\eta^2 = .757$, and a main effect of difficulty, $F(1,4) = 23.68$, $p = .008$, $\eta^2 = .855$.

To examine the effect of decision difficulty on RTs in each group, within-group comparisons were performed on pooled data from the Roundness and Open Eyes conditions. Paired-samples t-tests showed the amygdala group took longer to make decisions in high difficulty trials ($M = 2.23$, $SE = 0.54$) compared to low difficulty trials ($M = 1.89$, $SE = 0.44$), $t(2) = -10.81$, $p = .008$, whereas there was not a significant effect of difficulty on RTs in the control group (High difficulty: $M = 1.95$, $SE = 0.17$; Low difficulty: $M = 1.89$, $SE = 0.23$), $t(2) = -0.78$, $p = .515$.

Social vs. Non-social Preference

The ANOVA comparing the Nature Scenes condition to Open Eyes revealed no significant interactions, nor a main effect of group (ps > .118).

Inverse Efficiency Scores

Lastly, we checked for a speed-accuracy tradeoff by analyzing RT and accuracy together, computing inverse efficiency scores (i.e., reaction time divided by accuracy) for each participant and condition in the low difficulty trials. A 2 x 4 ANOVA with a between-subjects factor of group and within-subjects factor of condition indicated there was no interaction between condition and group ($p = .292$) and no significant difference between groups ($p = .838$).

3.3.3 Discussion

We tested three patients with rare amygdala lesions to examine whether social processing impairments would affect preference decisions for faces and the temporal evolution of those decisions. Interestingly, amygdala lesions patients demonstrated an intact feedback loop linking gaze and preference for faces and made similar preference choices as controls. There were, however, hints in the fixation behavior of the amygdala group, suggesting that there are underlying differences in the pattern of gaze towards faces.

Due to the small sample size, group comparisons lacked the statistical power to allow us to draw quantitative conclusions. There were, however, notable qualitative trends in the data worthy of discussion that I will review briefly in this section.

At the individual level, the gaze cascade effect was observed for each of the amygdala subjects in all four conditions, indicating that the feedback loop between preference and foveation is normal and intact in the amygdala lesions subjects. At the group level, the sigmoid curves fit to the raw data were generally similar between groups. With the exception of the Open Eyes condition, inspection of the confidence bounds did not reveal any significant differences in the four parameters describing each group's sigmoids. In the Open Eyes condition, the sigmoid for the amygdala group rose more rapidly than it did for controls, and also reached a higher plateau. This suggests there may be an underlying difference in the time course of face preference formation in the amygdala group. Moreover, the sigmoid curves appeared similar across the four conditions in the amygdala group whereas the sigmoid curves are notably different across conditions for healthy controls, indicating that the amygdala group demonstrated relatively invariant gaze during decision-making, regardless of task or stimulus type. Preference decisions were also similar between groups, at least in the low difficulty trials, as indicated by the relatively similar beta weights resulting from the linear regression in the low difficulty trials. While between-group correlations for preference choice in the low and high difficulty trials did not reach significance in the preference decision tasks, this is likely due to an issue of the statistics being underpowered.

Analysis of gaze behavior indicated that fixation patterns towards faces were likely different in patients with amygdala lesions relative to controls. First, fixation durations were longer for the amygdala group than the control group, particularly for preference decisions regarding faces. In both the Open Eyes condition and the Timed condition, the amygdala subjects made longer fixations relative to controls, while in the Nature Scenes condition, they made shorter fixations than controls. Moreover, when we compared fixation rates in each condition (fixations per second), there was a trend for noticeably slower fixation rates in the Open Eyes condition and Timed conditions, marginally slower rates in the Roundness conditions, and no difference in the Nature Scenes condition. In other words, the amygdala group made fewer and longer

fixations for decisions involving face preference, but not nature scenes or objective decisions for faces. Longer fixations are generally believed to be an indication of difficulty extracting information (Fitts, Jones, & Milton, 1950; Goldberg & Kotval, 1998; Rayner et al., 2007). On the other hand, they could also indicate increased engagement with the stimuli (Poole & Ball, 2014). Moreover, fixation rates might also simply reflect the speed of processing in mental tasks (Kahneman, 1973). Hence, there is at least weak (however, non-significant) evidence for preference decisions involving faces to be associated with amygdala-functioning.

There was also a trend for longer latency to first fixation on a stimulus in the amygdala group compared to controls. This effect was observed in all four conditions, which could be associated with slower mental processing or could suggest a lack of interest in initially engaging with the task. Though there were no differences in basic motor response times, the longer reaction times in the Open Eyes and Timed conditions suggest that the amygdala subjects were slower to make preference decisions for faces but not for nature scenes or face roundness.

The lack of systematic group differences in the gaze cascade curves and the relatively similar preferences in the amygdala lesion group relative to controls suggests that the amygdala is not required for forming preferences for social stimuli. While the amygdala plays a crucial role in processing faces and emotions, lesion effects might be stronger for tasks involving emotional processing rather than general face processing, since general face processing relies more on the fusiform gyrus and superior temporal sulcus (Haxby, Hoffman, & Gobbini, 2002). Alternatively, it may be the case that other brain regions have compensated for the processes impaired by amygdala lesions. Indeed, there is evidence suggesting that some amygdalar functions can be partially compensated for, such that certain aspects of social processing, such as theory of mind (Shaw et al., 2004) and fear recognition (Becker et al., 2012) appear to remain intact or only moderately impaired (Brierley, 2004).

In sum, while there were qualitative trends in the data suggesting there are underlying differences in patterns of face gaze in amygdala participants, the comparisons of gaze behavior and reaction time did not yield significant group differences with the exception of the gaze

cascade curve for the Open Eyes condition. The absence of significant effects in our study may have been due to small sample sizes. Only significantly large effects would be detectable in such a small group comparison and it may be the case that differences would be observed with a larger sample size. Thus, while our findings suggest that the amygdala does not play a critical role in face preference formation, future studies using larger sample sizes will be necessary to elucidate if this conclusion holds true.

3.4 Familiarity versus Novelty Study in Autism

3.4.1 Introduction

In a paradigm by Park, Shimojo, and Shimojo (2010), which we applied in an adapted version for the present study, researchers showed participants pairs of faces and pairs of nature scenes and asked them to judge the pictures for preference (Park et al., 2010). In each pair, one picture was novel, and the other picture was familiar (i.e., the picture was presented in every trial). They found that for nature scenes, participants demonstrated a "novelty bias" in that participants grew to prefer the novel nature scenes over the familiar nature scenes. However, for the pictures of faces, they found that participants demonstrated a "familiarity bias" in that participants developed a preference for the familiar face and were more likely to choose the familiar face over the novel faces. A follow-up study further refined these results, reporting that familiar faces were preferred both in contexts where those faces were passively viewed and when an explicit judgment had to be made about them, whereas the novelty preference for nature scenes occurred only in the latter context (Liao et al., 2011).

Several interacting factors have been proposed in order to explain the differential preference principles seen in the different stimulus categories. One is the level of experience we have with certain types of stimuli. People are subconsciously driven to acquire more knowledge about faces than virtually any other object categories from birth to adulthood (Fagan, 1972; Goren et al., 1975; Walton & Bower, 1993). Given the larger range of within-category variability for nature scenes compared to faces, and the relative lack of nature scene expertise compared to face expertise (and by implication, the brain regions and networks attuned to evaluating them), it could be that people orient toward novel rather than familiar nature scenes in an attempt to understand the naturally-occurring parameters of such stimuli (Park, 2010). In contrast, faces are relatively invariant, and as such, the bounds might be much more easily and quickly determined. One could imagine then that while it would be valuable for survival to attend to novel nature scenes to acquire expertise regarding one's environment, it would similarly be advantageous to orient toward familiar faces and learn to evaluate them for subtle differences to enrich and refine discrimination skills. Furthermore, as a result of life-long orienting toward

social stimuli, we acquire a vast amount of knowledge about how to read faces. In this respect, social attention and one's level of face expertise could influence the preference for familiar faces. Forming a familiarity preference also requires memory for faces (and by extension, the ability to form category representations of faces), because the face must be encoded to memory in order for it to be recognized as familiar when it is encountered again.

Another factor is the level of processing demands of each stimulus category. Social processing requires the evaluation of faces, and for most people, evaluating faces occurs automatically, holistically, and subconsciously. In contrast, people are not often asked to make evaluations of nature scenes and as such the processing load may be higher for nature scenes than faces. This, in turn, could influence whether we prefer a familiar or novel stimulus. On the other hand, one could also argue that social stimuli such as faces are more complex than non-social stimuli, and as such, require greater attention than nature scenes, which could also influence our preference. Thus, there are a variety of factors strongly linked to social saliency that could interact to produce a familiarity preference for faces (and not for non-social stimuli), including social attention, level of face expertise, social memory, and processing abilities.

As discussed previously in Chapter I, aspects of social processing that are compromised in ASD might be linked to amygdala dysfunction. Faces are less likely to draw the attention of people with autism, who show reduced social orienting and social attention to social stimuli than their neurotypical counterparts (Dawson et al., 2004). It has been argued that these deficits could stem from a failure of the amygdala to assign social saliency to faces (Aggleton, Burton, & Passingham, 1980) and signal feedback pathways necessary for processing social stimuli (Schultz, 2005).

While the evidence is mixed, there are also some studies that show that deficits in social processing could directly affect face recognition abilities (for a review, see Weigelt, Koldewyn, & Kanwisher, 2012). Studies have reported that individuals with autism show impaired memory for faces (Arkush, Smith-Collins, Fiorentini, & Skuse, 2013; Hauck, Fein, Maltby, Waterhouse, & Feinstein, 1998; Klin et al., 1999) and impaired immediate and delayed recall for faces and social scenes but not for non-social objects, though whether this impairment

applies only to unfamiliar faces is less clear (Boucher & Lewis, 1992). People with ASD also demonstrate abnormal face coding mechanisms (Pellicano, Jeffery, Burr, & Rhodes, 2007) and are impaired in their ability to form abstract representations of categories for both faces and non-face stimuli (Gastgeb, Rump, Best, Minshew, & Strauss, 2009; Klinger & Dawson, 2001), which would likely contribute to impairments in encoding and consolidating memory for faces. And finally, people with ASD show less accurate memory awareness for faces, meaning that even when they show deficits in face recognition, they have difficulty recognizing their own impairment (Wilkinson, Best, Minshew, & Strauss, 2010).

Given the deficits in social processing in autism, we examine whether face preference formation according to familiarity is impaired in autism. Subjects were shown pairs of social and pairs of non-social stimuli and asked to make a 2-alternative forced choice for which stimulus was preferred. For each image subcategory, one stimulus in a pair was repeated in every trial. We found similar patterns of preference segregation in the ASD group relative to controls, for both types of stimuli: ASD subjects showed a preference bias for face stimuli and a novelty bias for nature scene stimuli. The results suggest that face preference formation for familiar faces might be spared from social processing deficits typically observed in autism.

3.4.2 Materials and methods

3.4.2.1 Participants

Participants were a group of n =12 high-functioning subjects with a DSM-IV diagnosis of Autism Spectrum Disorder ranging in age from 22 – 58 years old (M_{age} = 33.0 years, SD = 12.5) and included 9 males and 3 females. Sample size was determined by participant availability. DSM-IV diagnosis was confirmed by the Autism Diagnostic Observation Schedule (ADOS; (Lord et al., 2000) and either the Autism Diagnostic Interview-Revised (ADI-R; (Lord et al., 1994) or the Social Communication Questionnaire (SCQ; (Rutter et al., 2003). The autism comparison group consisted of 12 healthy controls ranging in age from 21 – 59 (M_{age} = 31.7 years, SD = 11.2), and included 10 males and 2 females. The comparison group was matched on age, gender, and IQ, with no family history of psychiatric illness. Demographic and diagnostic information for the autism and control participants is found in Table 3.12.

Table 3.12. Demographic and diagnostic information for autism and control participants in the Familiarity/Novelty study.

	Autism group					Autism group: ADOS	
	Sex	*Age*	*Verbal IQ*	*Full scale IQ*	*AQ*	*SOC*	*COM+SOC*
1	F	22	102	107	28	14	21
2	M	30	111	106	30	11	17
3	M	57	119	102	33	8	12
4	M	31	127	124	22	7	11
5	M	29	117	115	39	14	20
6	F	37	135	133	41	9	13
7	M	26	89	93	31	7	10
8	M	23	90	100	22	10	16
9	F	19	128	124	31	6	9
10	M	32	97	99	34	10	14
11	M	32	50	91	26	11	15
12	M	58	118	126	34	7	9
Mean		33.00	102.50	108.50			
SD		12.48	22.40	13.03			

	Control group				
	Sex	*Age*	*Verbal IQ*	*Full scale IQ*	*AQ*
1	M	44	122	116	-
2	M	59	109	105	-
3	M	23	123	123	12
4	M	21	120	121	-
5	M	37	108	120	-
6	M	34	125	132	-
7	M	25	106	107	8
8	F	33	104	97	11
9	M	21	104	109	25
10	M	21	104	101	18
11	M	31	95	104	15
12	F	31	97	91	12

13	M	44	122	116	-
Mean		31.67	106.62	105.54	
SD		11.23	9.43	7.04	

a. Verbal IQ and full-scale IQ from the Wechsler Abbreviated Scale of Intelligence; AQ: Autism Spectrum Quotient; ADOS: Autism Diagnostic Observation Schedule; SOC: social interaction subscale; COM+SOC: communication+social interaction subscales

T-tests showed that the groups were not significantly different in terms of age $t(22) = -0.22$, $p = .832$, IQ, $t(22) = .094$, $p = .493$, as measured by the Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999), or gender ($p = .10$, 2-sided Fisher's Exact Test). All participants gave written informed consent to participate under a protocol approved by the Institutional Review Board of the California Institute of Technology.

3.4.2.2 Stimuli and apparatus

Stimuli consisted of pairs of social stimuli (computer-generated human faces) or pairs of non-social stimuli (nature scenes). Male and female face images were generated using Facegen (Singular Inversions, Vancouver, Canada), and were shown front-facing with neutral emotional expression and direct eye contact. Nature scenes were sourced from a google image search for "desert" and "mountain".

To control for preference bias due to differences in baseline attractiveness of the stimuli, all images were drawn from a larger set of face and nature scene stimuli pre-rated for attractiveness by a separate group of non-autistic participants on a scale of 1 (very unattractive) to 7 (very attractive) ($n = 20$, Females = 8; $M_{age} = 28.2$ years, $SD = 7.5$).

We created 20 image pairs in each of the four subcategories (male faces, female faces, mountain scenes, desert scenes) using the following procedure for each subcategory: we selected the median-rated image in each subcategory as the "familiar" image and presented it in every trial, pairing it with a "novel" image chosen from the same subcategory. Images were paired such that in half of the trials, the familiar image was more attractive, and in half of the trials, the familiar image was less attractive. To control for preference bias based on

attractiveness, within each each group, pairs were presented such that half the participants saw the familiar image paired with a more attractive image, and half saw the familiar image paired with a less attractive image. Each image pair was presented in randomized order once per block, and the location of each image in a pair was left-right randomized.

Images were presented on a 21" CRT monitor with a refresh rate of 100 Hz and pixel resolution of 1152 x 864. The stimuli in each test pair were presented simultaneously on the left and right side of the screen. At a viewing distance of approximately 57 cm, each stimulus pair had an overall size of 36.2 (width) x 14.4 (height) degrees of visual angle.

Stimuli were presented using Matlab (Mathworks, Natick, MA), the Psychophysics toolbox (Brainard, 1997), and the Eyelink toolbox (Cornelissen et al., 2002). Gaze data was collected using a head-mounted Eyelink II eye-tracking system (SR Research, Osgoode, Canada). Corneal and pupil reflection were recorded at a sampling rate of 250 Hz. At the beginning of each block, a 9-point calibration was performed. Each trial began by requiring subjects to fixate on a central drift correction dot. After the eye-tracker registered a successful fixation, participants pressed the space bar to start the trial.

3.4.2.3 Procedure

Subjects performed a 2-alternative forced-choice (2AFC) task, making self-paced preference decisions while eye-gaze was tracked (see Figure 3.12). Subjects inspected a pair of simultaneously presented stimuli, then made a 2AFC choice by pushing either the left or the right button.

Experimental design consisted of two blocked conditions in which participants viewed pairs of social stimuli (Faces) or pairs of non-social stimuli (Nature Scenes). There were 2 subcategories in each category (Faces: male, female; Nature Scenes: mountains, desert), and 20 trials in each subcategory (see Figure 3.12 for summary of experimental conditions and sample stimuli). Category and sub-category order was counter-balanced across subjects.

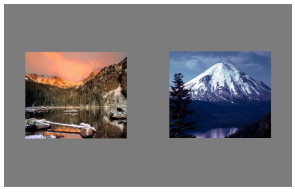
Category	Sub-category	Example Stimuli	Trials
Faces	Female		20
	Male		20
Nature Scenes	Desert		20
	Mountain		20

Figure 3.12. Summary of experimental conditions and example stimuli. Median-rated picture is shown on the left.

3.4.2.4 Analyses

Each subject's preference choice was converted to a familiarity or novelty score, "1" if the familiar picture was chosen, and "-1" if the novel picture was chosen. Familiarity-novelty scores were then averaged across subcategories and across subjects in each group for each sequential trial.

For statistical analysis of the familiarity-novelty scores, we ran repeated-measures ANOVAs with a between-subjects factor of group (ASD, control), and within-subjects factor of image category (Face versus Nature Scene) or subcategory (female versus male; desert versus mountain). To compare the initial preference in the first trial to the final preference in the last

trial across image categories, we ran one repeated-measures ANOVA with within-subjects factors of time (first trial, last trial) and image category (faces, nature scenes).

To compare the initial stage of preference development to the later stage of preference development in the image categories, we averaged the first five trials and the last 15 trials in each category and ran an ANOVA, using a within-subjects factors of time (first five trials, last 15 trials) and image category (faces, nature scenes). To compare stages of preference development in the *subcategories*, we re-ran a similar ANOVA on the averages of the first 5 trials and the last 15 trials in each subcategory, using a within-subjects factor of image subcategory (female faces, male faces, nature scenes, desert scenes).

Second, we explored initial gaze by analyzing the eye-tracking data in two ways: analyzing the proportion of first fixations that were made to the novel image versus the familiar image, and the proportion of first fixations that were made to the eventually chosen image versus the unchosen image. For each of these two measures, we carried out a repeated-measures ANOVA using as within-subjects factor of image subcategory and between-subjects factor of group. Lastly, we carried out one-sample t-tests in each subcategory to determine if any of the proportions differed significantly from chance.

3.4.3 Results

3.4.3.1 Familiarity-Novelty scores

The time-course of preference bias in the two stimulus categories is shown below in Figure 3.13. The first ANOVA comparing familiarity/novelty scores in the first trial and last trial in the two image categories (faces, nature scenes) indicated there were no significant interactions involving group (all *p*s > .413) and no main effect of group ($p = .383$), indicating the likelihood of preferring the familiar image in the first trial and last trial did not differ between groups in the two image categories. There was an interaction between time and category, $F(1,22) = 4.50$, $p = .045$, $\eta^2 = .170$, indicating that, regardless of group, there was a stronger familiarity preference for faces in the final trial relative to the first trial, (First trial: $M = -.125$, $SE = .164$; Last Trial: $M = .125$, $SE = .154$), whereas there was a stronger novelty preference for nature

scenes in the last trial compared to the first trial (First trial: M = .000, SE = .136; Last Trial: M = -.458, SE = .122). None of the main effects were significant.

The ANOVA comparing the first five trials and last 15 trials across the two image categories also indicated there were no interactions involving group (all ps > .156) and no main effect of group (p = .365), signifying that preference development in the stimulus categories did not differ between groups in the initial trials nor the later trials. There was a significant interaction between time and category, $F(1,22)$ = 10.48, p = .004, η^2 = .323, revealing a significant difference in preference bias within the first five trials, for familiarity in the face category but novelty in the nature scenes category, (Faces: M = .142, SE = .083; Nature scenes: M = -.233, SE = .088; $t(23)$ = -2.67, p = .014). The respective biases were also significantly different in the last 15 trials, (Faces: M = .300, SE = .077; Nature scenes: M = -.431, SE = .063; $t(23)$ = 7.71, p < .001). Furthermore, within image categories, there was a stronger familiarity bias for faces in the last 15 trials than in the first five trials, $t(23)$ = -2.05, p = .052, whereas there was a stronger novelty bias for nature scenes in the last 15 trials than in the first five trials, $t(23)$ = -3.55, p = .002.

Lastly, there was a significant main effect of category, $F(1,22)$ = 25.67, p < .001, η^2 = .539, indicating a stronger familiarity preference for faces regardless of time or group, and a stronger novelty preference for nature scenes regardless of time or group (Faces: M = .553, SE = .109; Nature scenes: M = -.553, SE = .109).

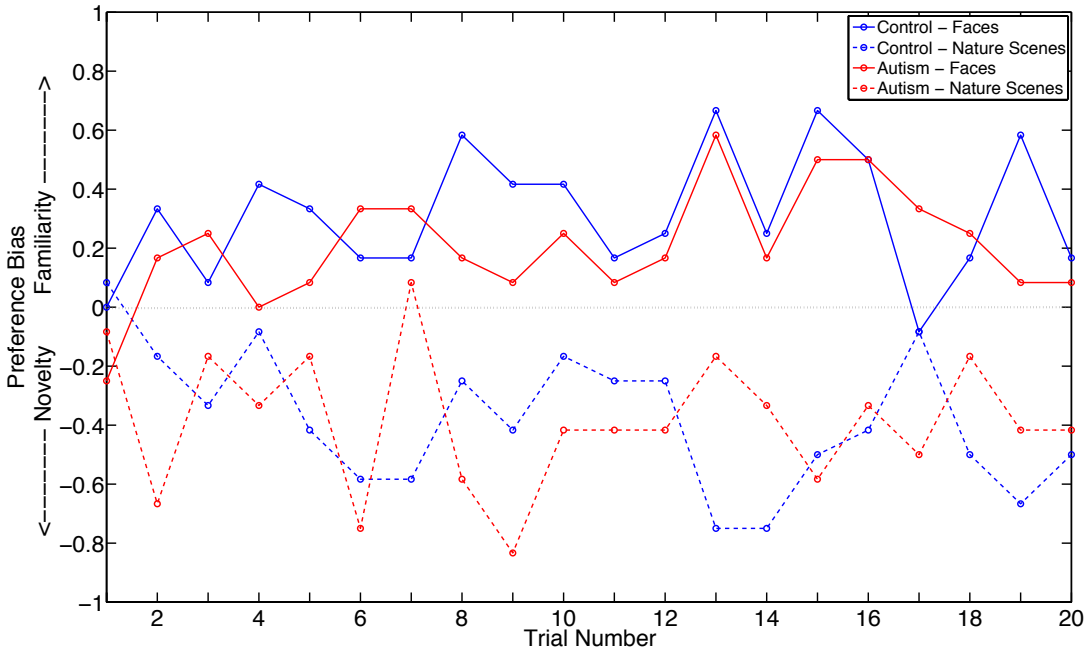


Figure 3.13. Time-course of familiarity/novelty preference bias over 20 trials, collapsed across sub-categories in each image category. The two categories consist of Face (sub-categories: female and male), and Nature Scenes (sub-categories: desert scenes, mountain scenes).

The time-course of preference bias in the four image subcategories is shown below in Figure 3.14. The ANOVA comparing the first five trials and last 15 trials across the four image subcategories indicated that there were no interactions involving group (all *p*s > .156) and no main effect of group ($p = .365$), meaning preference development in the image subcategories did not differ between groups in the initial trials nor the later trials. There was a significant interaction between time and subcategory, $F(3,66) = 4.16$, $p = .009$, $\eta^2 = .159$, which we followed up with pairwise comparisons.

Pairwise comparisons between image subcategories for the first five trials indicated there was a significant difference in preference bias between female faces and mountain scenes (Female faces: $M = .067$, $SE = .112$; Mountain scenes: $M = -.333$, $SE = .107$; $t(23) = 2.18$, $p = .040$) , and between male faces and mountain scenes (Male faces: $M = .217$, $SE = .103$; Mountain

scenes: M = -.333, SE = .107s; $t(23) = 3.45$, $p = .002$). None of the pairwise comparisons involving desert scenes were significant.

Pairwise comparisons of subcategories in the last 15 trials also indicated that all four subcategories differed significantly from each other. Participants demonstrated the strongest familiarity preference for male faces (M = .433, SE = .071), followed by female faces (M = .167, SE = .111), and a moderate novelty preference for desert scenes (M = -.294, SE = .112), as well as a strong novelty preference for mountain scenes (M = -.567, SE = .062).

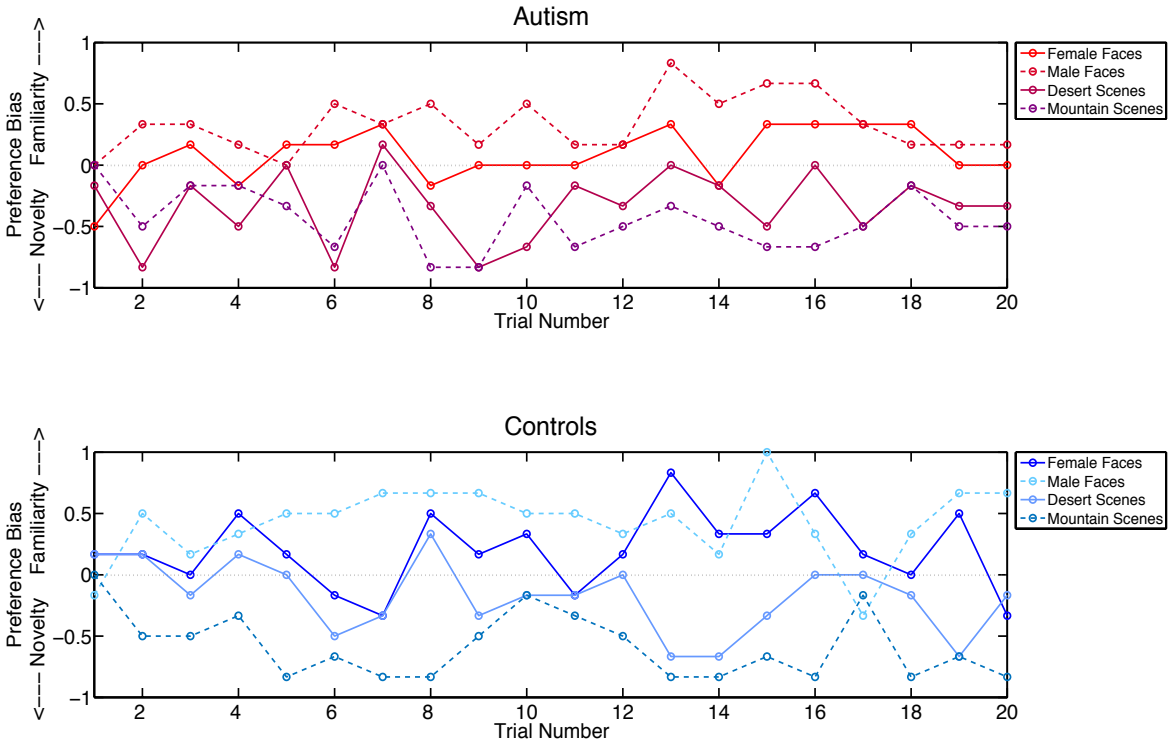


Figure 3.14. Time-course of familiarity/novelty bias in the ASD group (top) and Control group (bottom) divided by sub-categories.

3.4.3.2 Likelihood of initial fixation on novel image

A repeated-measures ANOVA was carried out comparing the proportion of trials in which the first fixation on an image was on the novel image, using as within-subjects factor image subcategory and as between-subjects factor group. There was no significant interaction between group and subcategory (p = .717) or a main effect of group (p = .275). There was, however, a main effect of subcategory, $F(3,66) = 13.53$, $p < .001$, $\eta^2 = .381$, showing that regardless of group, participants were significantly more likely to initially fixate on the novel nature scene image (M = 65.8 %, SE = 2.5) than the novel face image (M = 50.3 %, SE = 1.4). Follow-up comparisons indicated that there were no differences in first fixation likelihood between images in the same sub-category.

One-sample t-tests in the face category indicated that the likelihood of initial gaze to the novel image did not differ significantly from chance for either female faces (M = 50.7%, SE = 1.7; $t(23) = -0.32$, p = .749), or male faces, (M = 50.0%, SE = 1.8; $t(23) = 0.00$, p = 1.00), whereas in the nature scenes category, participants were significantly more likely to make the initial fixation to the novel image, for both desert scenes, (M = 68.9%, SE = 3.5; $t(23) = -5.28$, $p < .001$), and mountain scenes, (M = 62.8%, SE = 2.5; $t(23) = -4.98$, $p < .001$) . Results are summarized in Figure 3.15.

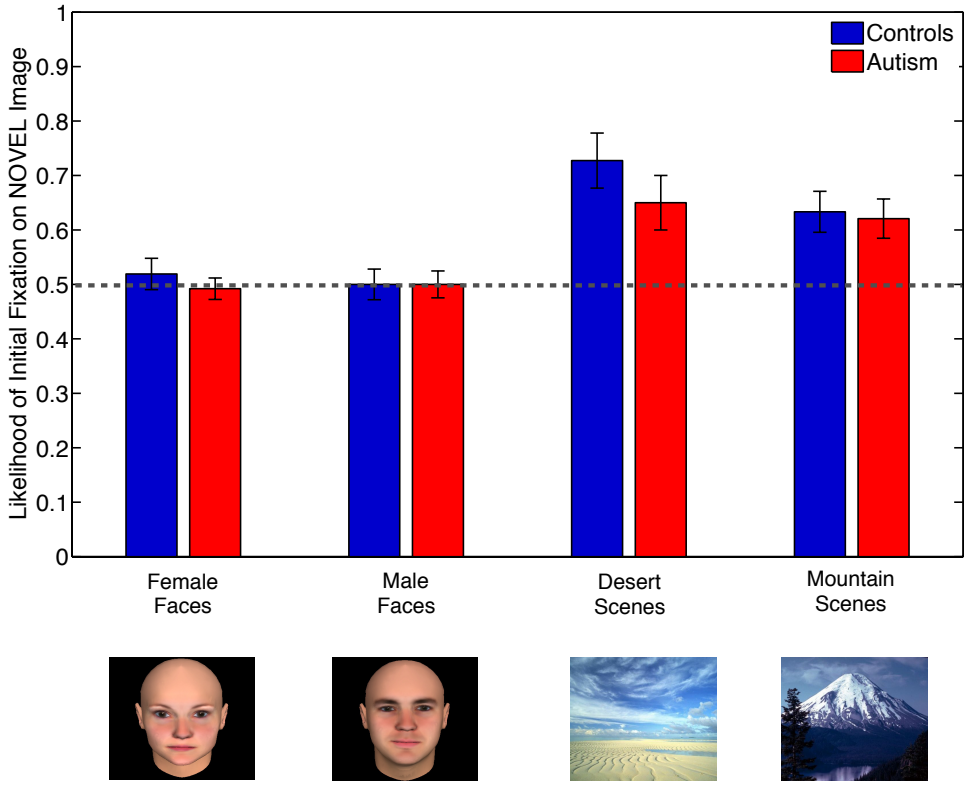


Figure 3.15. The probability of initial gaze on the novel image plotted against stimulus type. Dashed line indicates chance (50/50) likelihood. Error bars denote standard error.

3.4.3.3 Likelihood of initial fixation on eventually-chosen image

A repeated-measures ANOVA comparing the proportion of trials in which the first fixation on a stimulus was on the eventually chosen image indicated that there was no significant interaction between group and category, no main effect of group, and no main effect of category (all *p*s > .547).

One-sample t-tests indicated participants were significantly less likely to make the initial fixation to the image eventually chosen in all image subcategories, for female faces (M = 36.3%, SE = 2.9; $t(23) = -4.70$, $p < .001$), male faces, (M = 37.1%, SE = 3.2; $t(23) = -3.99$, p = .001), desert scenes, (M = 33.4%, SE = 3.2; $t(23) = -7.11$, $p < .001$), and mountain scenes, (M = 33.5%, SE = 2.8; $t(23) = -5.69$, $p < .001$) . Results are summarized in Figure 3.16.

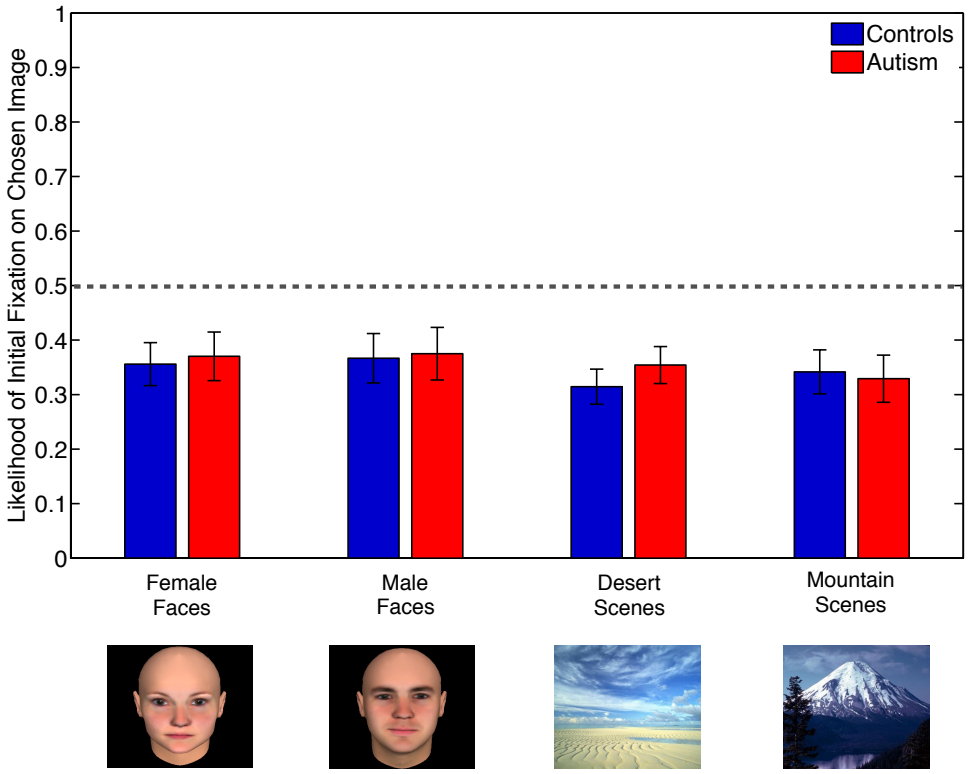


Figure 3.16. The probability of initial gaze on the image that was eventually chosen plotted against stimulus type. Dashed line indicates chance (50/50) likelihood. Error bars denote standard error.

3.4.4 Discussion

In the present study, we explored category-specific familiarity and novelty principles in high-functioning autism. We found there were similar patterns of preference segregation between groups, such that people with ASD developed a familiarity preference for faces and a novelty preference for nature scenes, similar to controls' preferences. In addition, we found that patterns of initial gaze did not differ significantly between groups, such that both groups made similar proportions of their initial fixations to the familiar stimulus, and to the image that was eventually chosen.

Repeated visual exposure to stimuli often increases preference for those stimuli. This familiarity preference has been shown to be specific to certain object categories, such as faces, whereas a novelty preference has been observed for non-social images. Here we found a strong familiarity preference, with no difference between groups, for the face that was presented in all 20 trials. There was also a strong preference in the opposite direction with nature scenes for the novel image also presented in each of the trials. The overall results replicate the segregation of preference bias reported by Park et al.'s (2010) original study.

The familiarity preference for faces and nature scenes was apparent quickly (within the first 5 trials), again with no significant difference between the autism and control group. It is interesting to note, however, that while the male and female faces differed significantly from the mountain scenes, none of the pairwise comparisons involving the desert scenes were significant, indicating a lack of initial bias for the desert images. This may be because desert images generally show less variability in color range and contrast than mountain images, making them less visually appealing, or perhaps because the images that were chosen were not particularly compelling enough to inspire a preference bias in the initial stages.

On average, the preference biases for familiar faces and novel nature scenes were present through the remainder of the trials, with participants showing the strongest familiarity preference for male faces, followed by female faces, and the strongest novelty preference for mountain scenes, followed by a weaker novelty preference for desert scenes. Since these results did not differ between groups, they suggest that the ability to form category-specific preferences, as well as maintain those preferences, is not significantly compromised in high-functioning autism.

Evidence in support of intact preference formation is also seen in the lack of group differences in likelihood of initial gaze to the familiar image. Participants were more likely to make the initial fixation in a trial on the novel nature scene image than the novel face image, suggesting first that the use of top-down attentional strategies can likely be ruled out since these differences were apparent at the first fixation, presumably before participants had the opportunity to foveate on the images and determine consciously which image was the familiar

one. Second, the similarity between groups in likelihood of initial fixation to the familiar image also suggests there is a shared underlying mechanism functioning pre-attentively to direct visual attention, rather than a post-hoc attentional strategy. While the findings reported here are mostly negative (i.e., n.s.) relative to the controls, there are significant implications owing to the baseline positive results in the controls. Once again, it indicates that despite social impairments in ASD, certain aspects of face processing remain intact or can be compensated for by people with ASD to result in similar preference decisions as those made by controls.

While our findings point to normal preference formation in autism, there are several open questions for future studies. Given the significant amount of noise in each trial for both groups, averaging across a larger number of subcategories could reduce the variability and perhaps reveal differences in the time-course of preference development that were obscured in the present study. This could be achieved by running either more repetitions of the existing subcategories or using a greater number of sub-categories.

Future studies could also investigate individual familiarity and novelty preferences within subjects. Given the putative preoccupation with non-social stimuli in autism, familiarity preferences may occur in different object categories for different subjects. A study in which pre-ratings are obtained from each participant for different stimuli categories, and then used to construct image pairs could be informative to understanding if there are subject-specific areas of "expertise" that would elicit a familiarity bias similar to faces. Future studies could also use multiple social stimuli to provide greater ecological validity, since many social situations involve more than one or two others. It could be the case that deficits are only present, or become apparent, when there are more visual and social stimuli competing for attention.

Lastly, it is unclear even in neurotypicals, whether the face familiarity preference is restricted to realistic faces and whether it would extend to face-similar categories, such as schematic faces, paintings of faces, or "man on the moon" type visual effects. Would people with autism see faces in non-face objects (face-similar objects)? In other words, what level of abstraction would be necessary to eliminate the preference bias for faces? Moreover, where is the boundary between face and non-face in autism and in neurotypicals? It would be enlightening for our

understanding of face processing, both in neurotypicals and in individuals with autism, to explore to what degree of abstraction the brain will still respond to by forming a familiarity preference, as it would suggest what some of the necessary elements are for face perception and categorization, as well as for our emotional response to faces.

3.5 Conclusion

In this chapter, I explored whether social processing deficits in people with autism and amygdala lesions would also affect subjective preference formation for faces. I found that the feedback loop between foveation and preference formation remained intact in people with autism and amygdala lesions, and furthermore, that they made similar preference decisions as controls. I also found similar patterns of preference *bias* segregation in the ASD group relative to controls, for both social and non-social stimuli: ASD subjects demonstrated a familiarity bias for face stimuli and a novelty bias for nature scene stimuli. However, I also found that people with autism had faster reaction times for face preference decision, and their reaction times were insensitive to decision difficulty. The findings indicate that while face preference formation is spared from social processing deficits typically observed in autism, there are differences in the behavioral strategy used by individuals with autism.

The results from these studies are consistent with findings showing high-functioning autistic individuals' ability to process more basic social information is not reliably affected by the face processing deficits commonly observed in autism. One explanation for the lack of impairment in face preference formation is that face perception in a subjective context could require less complex social processing compared to face perception in an objective decision-making task, or in complex social interactions. For example, a lower level of face processing ability may be sufficient to form a face preference versus correctly identifying a familiar face, which requires explicitly relating face identity to contextual and biographical knowledge. In this sense, less complex aspects of social processing such as the recognition of basic emotions or the formation of preference for certain faces might be spared from deficits commonly observed in processing of more involved aspects of facial and emotional expressions, such as recognizing intentions or judging more complex mental states.

An alternative issue to consider given the relatively high-functioning ability of the autism subjects in the current studies is the issue of compensatory functioning, both in the neural sense and in the behavioral sense. Face preference formation could very well *appear* to operate normally despite an underlying impairment in processing. There are multiple pathways for processing of social information, some of which could partially compensate for social

processing functions that are compromised in autism and amygdala lesion patients. Compensatory social processing from other brain regions could be sufficient for the formation of social preference.

Moreover, the ability to process more basic social information in high-functioning autism can also be facilitated with the use of atypical, and perhaps top-down, compensatory behavioral strategies. I found evidence for this possibility in the faster reaction times for face preference decisions in the autism group, and the insensitivity of their reaction times to the difficulty of the preference decision. Given the lack of preferential attention to social stimuli, the use of atypical compensatory strategies might allow for a choice criterion to be reached in ASD quickly and without regard to the relative attractiveness of the faces. The possibility that atypical or compensatory strategies could mitigate the appearance of social deficits of course poses challenges for how to study impairments in face processing, a topic which we examine in the next chapter, the Don't Look study.

Chapter IV

TASK-DEPENDENT MODULATION OF FACE GAZE

4.1 Overview

The third and final study in this dissertation is the "Don't Look" study. The purpose of this experiment was to investigate the flexibility of face scanning strategies used by individuals with high-functioning autism and amygdala lesion patients. Participants were instructed to view faces while avoiding specific facial features, so we could investigate strategies for face exploration and the ability to update those strategies under changing viewing contexts.

In exploring why some aspects of gaze and preference behavior in ASD appeared no different from healthy controls in the prior studies, I became familiar with a growing discussion in the literature regarding inconsistent findings of social impairments in autism, particularly as they relate to deficits in face processing. As discussed in the Introduction of this dissertation, there are a variety factors that contribute to seemingly divergent findings for face processing in autism, including task demands and the characteristics of stimuli that are used. For example, differences in stimuli can affect the severity of social impairments in ASD, possibly due to the greater cognitive effort required to process more complex social stimuli. Similarly, some studies have reported differences in eye gaze become more prominent in cognitively demanding tasks.

Another (not mutually-excusive) factor that can mitigate the effect of social deficits is the use of compensatory strategies during social processing in ASD. There is evidence to suggest that people with autism, particularly those who are high-functioning, compensate for social deficits by using atypical cognitive and visual strategies which give the appearance of behavior that differs very little from the behavior demonstrated by neurotypicals. Though these strategies are usually not as flexible or adaptive in situations that are unusual or require high cognitive effort, they are often sufficient for many other day-to-day situations.

Given that in the Gaze Cascade study, people with ASD demonstrated rather normal face gaze and faster reaction times relative to neurotypicals when making face preference decisions, we suggested that people with ASD may have approached the task as a perceptual task rather than a social one, i.e., the decision-making aspect of the task had mitigated or circumvented the effect of social impairments on gaze and attention. This is why, in the Don't Look study, our aim was to examine face gaze separate from an explicit decision-making task in order to understand how people with autism spontaneously look at faces.

To examine spontaneous face scanning strategies and the flexibility of those strategies, we designed a task in which we manipulated viewing strategies by giving instructions that were unrelated to our actual variables of interest: gaze to salient features of the face and propensity for face exploration. Subjects were instructed to avoid looking at the eyes while gaze to the remainder of the face was permitted, to avoid the mouth while gaze to the remainder of the face was permitted, or to look at the face without any restrictions.

The primary questions of our investigation were: 1) How do people with social processing impairments spontaneously explore the face (i.e., decoupled from social or explicit decision-making)? 2) How flexibly can face scanning strategies be adapted to changing social contexts? And 3) if face gaze strategies can mitigate the appearance of atypical face scanning, could these strategies be engaged elsewhere to elicit differences in viewing behavior?

The amygdala group demonstrated similar gaze patterns to salient face regions as controls and appeared equally flexible in gaze strategies. There was, however, a tendency in the amygdala group to look away from the salient parts of the face less often than controls, and also to look off the head less than controls.

There were notable differences in the autism group relative to controls. We found that while the general pattern of gaze on the screen and to salient features of the face appeared normal in high-functioning autism, there were differences between groups in the details of the ASD group's gaze pattern, and in the strategies they used in response to the viewing restrictions. Similar to controls, the ASD group spent the majority of gaze time looking on the face (rather than off the face), and in the conditions in which gaze to the eyes was allowed, both groups

spent the most time looking at the general eye region regardless of stimulus type. However we found that people with ASD showed impairments in orienting to the parts of the eye region that communicate the most information, instead showing a bias for looking between the eyes and at the nose. Furthermore, people with ASD showed deficits in adapting their usual strategies for face scanning while simultaneously adhering to the task restriction to avoid specific features, indicating there was reduced flexibility of those strategies in people with high-functioning autism. In summary, while individuals with ASD, at least superficially, did not appear to differ in the general pattern of gaze to larger regions of the face, there was clear evidence to indicate atypical face gaze in the details of visual behavior and in the flexibility of gaze strategies. The results from these studies suggest that face scanning utilizes general perceptual process that might not be reliant upon amygdala functioning.

4.2 Don't Look Study in Autism

4.2.1 Introduction

Autism spectrum disorder (ASD) is a developmental disorder characterized by a triad of deficits, consisting of impaired social interaction, impaired communication, and restricted interests and repetitive behaviors. Deficits in orienting toward and prioritizing social information are widely implicated in the social deficits observed in ASD. Studies have found that individuals with ASD demonstrate unusual attentional and viewing patterns towards social stimuli, showing reduced interest in socially salient stimuli, and particularly for faces, relative to their typically developing counterparts. People with ASD are slower to orient toward social stimuli (Fletcher-Watson et al., 2009; Freeth, Foulsham, & Chapman, 2011), are impaired in prioritizing social cues over non-social cues (Kikuchi et al., 2011; Klin et al., 2002), which could be accompanied by an attentional bias for non-social stimuli (Elison, Sasson, Turner-Brown, Dichter, & Bodfish, 2012; Pierce & Courchesne, 2001; Sasson, 2006) and show reduced interest in exploration of social stimuli (de Wit, Falck-Ytter, & Hofsten, 2008).

Face processing impairments are a characteristic symptom of Autism spectrum disorder, and behavioral abnormalities in this domain have been well-documented. Individuals with autism have difficulty with emotion recognition (Baron-Cohen et al., 1997; Hobson, 1986; Klin et al., 1999; Tantam et al., 1989), poor memory for faces (Boucher & Lewis, 1992; Klin et al., 1999; Teunisse & Gelder, 1994; Weigelt et al., 2012), and impaired perceptions of trustworthiness (Adolphs et al., 2001). The behavioral abnormalities are also supported by reports of abnormal brain activation during face processing in ASD (Dalton et al., 2005; Gotts et al., 2012; Koshino et al., 2008; Schultz, 2005; Whalen et al., 2004) implicating dysfunction in multiple neuroanatomical regions that are involved in face processing in typically developing individuals, including the fusiform face gyrus, amygdala, and superior temporal sulcus. In sum, people with ASD demonstrate impairments in processing and evaluating the social information conveyed by face stimuli.

Atypical social judgments in ASD might stem for abnormal gaze to faces. Overall, the current research indicates there are abnormalities in face gaze, however the results regarding the exact

nature of these abnormalities are mixed. Some studies have reported people with ASD pay more attention to atypical parts of faces, such as the nose and mouth, rather than the eye region as neurotypicals usually do (Hobson, 1986; Klin et al., 2002; Yi et al., 2013). However, there is also evidence to suggest that there is not a gaze bias for the mouth region (Bar-Haim, Shulman, Lamy, & Reuveni, 2006; Dalton et al., 2005; Rutherford & Towns, 2008). Similarly, while there is evidence of reduced gaze to all "core" features of the face (de Wit et al., 2008; Pelphrey et al., 2002), meaning the eyes, nose, and mouth, other studies have found no significant differences in gaze patterns to features of the face (van der Geest, Kemner, Camfferman, Verbaten, & van Engeland, 2002a; van der Geest, Kemner, Verbaten, & van Engeland, 2002b).

A key element of social impairment in ASD may be abnormal gaze to the eyes, though again the results have been mixed. While some studies failed to find differences in gaze to the eye region (de Wit et al., 2008; Fletcher-Watson et al., 2009; Rutherford & Towns, 2008; Sawyer, Williamson, & Young, 2012), other studies have reported diminished gaze to the eye region (Corden et al., 2008; Dalton et al., 2005; Klin et al., 2002; Pelphrey et al., 2002; Speer, Cook, McMahon, & Clark, 2007; Sterling et al., 2008). There is evidence to suggest that diminished eye gaze could be driven by a tendency to avoid direct eye contact and the general eye region, perhaps due to an underlying aversion to direct gaze (Dalton et al., 2005; Kliemann, Dziobek, Hatri, Steimke, & Heekeren, 2010; Tanaka & Sung, 2013). According to the theory of amygdala hyper-arousal, direct eye contact could cause a discomforting state of over-activation in the amygdala for individuals with ASD, which is subsequently compensated for by avoidance of direct eye contact (for a review of eye contact mechanisms in ASD, see Senju and Johnson, 2009). In contrast, people with autism might simply demonstrate a lack of preference for direct eye contact rather than actively avoiding it (Hernandez et al., 2009), due to hypo-arousal in response to social stimuli. The hypo-arousal account suggests amygdala under-activation results in reduced reward value (Dawson et al., 2004; Kohls et al., 2013) or reduced saliency of stimuli (Grelotti, Gauthier, & Schultz, 2002). Consequently, people with ASD might not learn to orient toward the eyes for social information, and as such do not develop a bias for the eye region. A refinement to this latter concept (Senju & Johnson, 2009; Senju, Tojo, Yaguchi, & Hasegawa, 2005; Senju, Yaguchi, Tojo, & Hasegawa, 2003) proposes that

there is no impairment in eye gaze in ASD but rather a lack of a facilitative effect of direct eye contact. Behavioral studies by Senju et al. report that people with ASD were equally efficient as controls in detecting averted gaze. With direct gaze, however, controls were faster and more accurate than with averted gaze, whereas people with ASD did not show an advantage for direct gaze relative to averted gaze. These results led the authors to suggest that direct gaze enhances performance in controls but not in people with ASD, and suggesting the putative eye gaze impairment in ASD was actually a lack of facilitative effect of direct eye contact.

It is important to note the results of many studies are often based on gaze to the general eye region, or gaze to the left and right eye combined. The results of a recent study (Yi et al., 2013) reported that while people with ASD did not differ from controls when comparing gaze to the eye region or both eyes combined, there were divergent results when the left and right eyes were analyzed separately. Several of the studies investigating gaze to the eye region use a single eye ROI approach (Bal et al., 2009; Fletcher-Watson et al., 2009; Klin et al., 2002; Sawyer et al., 2012) or combine the left and right eyes (Pelphrey et al., 2002; Sterling et al., 2008), which could confound differences in lateralization of gaze.

There are several experimental factors that likely contribute to the discrepancy in findings regarding social processing in ASD. One explanation is the effect of stimulus type and task demands used in the studies. A study by Speer, Cook et al. (2007) that directly tested the differential effects of stimulus types found that in contrast to studies reporting face processing deficits with simpler stimuli, people with ASD showed impairments only with complex dynamic stimuli, leading the authors to speculate that the impairments are associated with the greater cognitive demands for complex stimuli but not simple stimuli (Speer et al., 2007). Another possibility is that in structured experimental contexts (and presumably explicit task instruction), people with high-functioning autism do not experience the same difficulty attending to facial features and processing social information as they do in spontaneous and unstructured situations. In line with both of these ideas, it may be the case that face processing deficits in high-functioning autism would become apparent or more pronounced in situations

that require greater cognitive effort, for example when using more complex stimuli or unusual experimental paradigms.

Gaze to salient features may also change based on compensatory strategies, obfuscating spontaneous gaze tendencies. There is already evidence for the use of compensatory strategies in ASD, particularly in people who are high-functioning, that minimize the appearance of social impairments, for example, by relying on cognitive and verbal abilities during emotion recognition (Grossmann, 2000) and theory-of-mind tasks (Hadwin, Baron-Cohen, Howlin, & Hill, 1997; Ozonoff & Miller, 1995). There is growing evidence to indicate compensatory strategies also extend to face gaze. Some of these skills might consist of more effortful rule-based strategies that have been learned, for example increasing gaze to the mouth (Joseph & Tanaka, 2003) or eyes (Faja, Webb, Merkle, Aylward, & Dawson, 2009; Rice et al., 2012), while others may have been taught through interventional therapies for social skills (Tanaka et al., 2010; Teunisse & de Gelder, 2001) to facilitate social interactions. There is also evidence for the implicit (i.e., subconscious) use of visual strategies that can partially compensate for impaired social processes (Krysko & Rutherford, 2009; Leung, Ordqvist, Falkmer, Parsons, & Falkmer, 2013; Spezio et al., 2007).

While people with ASD may be able to use atypical strategies to partially compensate for social deficits, there is evidence to indicate that these strategies likely do not facilitate the processing and understanding of implicit social and emotional information in the same manner as in neurotypicals. For example, people with ASD who show little impairment in emotion recognition over a long response window still demonstrate impairments relative to controls during shorter response windows, indicating that the compensatory strategies being used were likely slower and more effortful (Celani, Battacchi, & Arcidiacono, 1999). Another study examining facial expression strategies found that the use of rule-based strategies in autism results in a greater tolerance for unnaturally exaggerated expressions (Rutherford and McIntosh, 2006), suggesting there is still an altered perception of emotions despite the use of these strategies. Consequently, people with autism may learn or acquire skills, which allow them to minimize the appearance of social deficits, but without developing an accompanying

understanding of the meaning of the strategy, making these strategies less flexible and adaptive than those used by neurotypicals.

The aim of the present study was to examine one of the most basic elements of social interaction, face scanning, to investigate atypical face gaze strategies that have been reported to compensate for social deficits and in particular, the flexibility of those strategies in response to changing viewing contexts. Specifically, we sought to examine gaze to salient regions of the face and the spontaneous tendency for face exploration under atypical viewing instructions. Eye-tracking was used to investigate gaze behavior in adults with high-functioning autism during a face viewing task which was decoupled from an explicit decision-making task. We utilized face stimuli depicting open eyes as well as closed eyes to investigate whether there was an effect of eye contact on face gaze. Participants viewed either faces one at a time and were given instructions to view the face freely or to look at the face while avoiding either the eyes or the mouth.

We hypothesized that for open-eyed stimuli, people with ASD would not show differences in gaze to salient facial features compared to controls. Consistent with evidence showing diminished sensitivity to the eyes rather than avoidance of the eyes in ASD, we also predicted that gaze behavior in ASD would remain the same for closed eyes stimuli as for open eyes stimuli. In the "Avoid the Eyes" condition we hypothesized that both groups would increase gaze to the mouth relative to the free-viewing condition and that the two groups would show little difference in gaze to remaining regions of the face. In line with reports of top-down strategies for face gaze in ASD, we predicted that in the "Avoid the Mouth" condition, cognitive control would be engaged avoiding the mouth. Consequently, there would be little spontaneous tendency for people with ASD to look at the eyes whether they were open or closed, whereas controls would look at the eyes as they did in the unrestricted condition. Therefore, we hypothesized that the ASD group would look less at the eyes relative to their eye gaze in Free View, and also relative to controls in this condition since cognitive strategies are engaged elsewhere. While there was a superficially normal tendency for people with ASD to look in the general eye region, we found differences in the distribution of gaze to the center of

the eye region and the right eye, and reduced flexibility of the strategies used for face scanning in ASD.

4.2.2 Materials and methods

4.2.2.1 Participants

Participants in the current study consisted of n = 12 (9 males, 3 females) high-functioning subjects with a DSM-IV diagnosis of Autism Spectrum Disorder ranging in age from 22-58 (M_{age} = 31.8 years, SD = 11.5). One additional ASD participant was tested but excluded from analysis due to equipment malfunctioning. Sample size was determined by participant availability. Diagnosis was confirmed using Autism Diagnostic Observation Schedule (ADOS; (Lord et al., 2000), the Autism Diagnostic Interview-Revised (ADI-R; (Lord et al., 1994), or the Social Communication Questionnaire (SCQ; (Rutter et al., 2003). ADOS Calibrated Severity Scores (Gotham, Pickles, & Lord, 2009), a metric for measuring symptom severity, were available for all but one of the ASD participants.

The comparison group consisted of n =13 healthy controls (10 males, 3 females) ranging in age from 24-54 (M_{age} = 34.9 years, SD = 11.6), group-matched for age, gender, and IQ, with no family history of psychiatric illness. All participants also completed the Autism Spectrum Quotient scale, or AQ (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001). Table 4.1 summarizes demographic and diagnostic information the participants in the autism and control group, respectively.

Table 4.1. Demographic and diagnostic information for autism and control participants in the Don't Look study.

	Autism group					Autism group: ADOS			
	Sex	*Age*	*Verbal IQ*	*Full scale IQ*	*AQ*	*SOC*	*COM+ SOC*	*CSS SA*	*CSS Overall*
1	M	26	131	133	32	9	13	9	9
2	F	26	123	125	35	4	7	5	6
3	M	48	115	109	37	6	8	7	9
4	M	42	80	93	20	14	20	10	10
5	M	25	87	103	21	11	16	10	10
6	M	58	118	126	36	7	9	7	7
7	M	30	111	106	28	11	17	--	--
8	M	26	94	106	28	8	12	8	7
9	F	22	101	102	33	13	20	10	10
10	F	22	102	107	32	14	21	10	10
11	M	33	50	91	31	11	15	9	8
12	M	24	118	101	14	7	12	6	5
Mean		31.83	102.50	108.50	28.92				
SD		11.51	22.40	13.03	7.13				

	Control Group				
	Sex	*Age*	*Verbal IQ*	*Full scale IQ*	*AQ*
1	F	38	104	102	11
2	F	29	116	116	9
3	M	32	119	117	18
4	M	45	85	97	18
5	F	24	95	100	11
6	M	24	111	109	12
7	M	52	111	108	17
8	M	25	106	107	11
9	M	24	97	94	26
10	M	27	108	111	15
11	M	54	113	109	5
12	M	51	108	102	15
13	M	29	113	100	6
Mean		34.92	106.62	105.54	13.38
SD		11.63	9.43	7.04	5.65

a. Verbal IQ and full-scale IQ from the Wechsler Abbreviated Scale of Intelligence; AQ: Autism Spectrum Quotient; ADOS: Autism Diagnostic Observation Schedule; SOC: social interaction subscale; COM+SOC: communication + social interaction

subscales; CSS SA: calibrated severity score – social affect; CSS Overall: calibrated severity score – overall.

Independent samples t-tests showed that the groups were not significantly different in terms of age ($t(23) = 0.67$, $p = .511$), gender ($p = .637$, 2-sided Fisher's Exact Test), and IQ ($t(23) = -0.72$, $p = .482$), as measured by the Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999). All participants gave written informed consent to participate under a protocol approved by the Institutional Review Board of the California Institute of Technology.

4.2.2.2 Stimuli and apparatus

Stimuli consisted of 144 computer-generated male and female faces, created with Facegen (Singular Inversions, Vancouver, Canada). Faces were front-facing with a neutral emotional expression (see Figure 4.1-A for sample stimuli). Half of the faces shown depicted open eyes and direct eye contact, and the other half depicted closed eyes. Each block had an equal number of faces with open eyes and closed eyes, and an equal number of male and female faces. No faces were repeated.

Images were presented on a 21" CRT monitor with a refresh rate of 100 Hz and pixel resolution of 1152 x 870. The stimuli were shown individually in the center of the screen for five seconds. At a viewing distance of approximately 52 cm, each face stimulus had an overall size of 22.9 (width) x 22.9 (height) degrees of visual angle.

Stimuli were presented using Matlab 2010a (Mathworks, Natick, MA), the Psychophysics toolbox (Brainard, 1997), and the Eyelink toolbox (Cornelissen et al., 2002). Gaze data was collected using the Eyelink 1000 remote eye-tracking system (SR Research, Osgoode, Canada). Corneal and pupil reflection were recorded at a sampling rate of 500 Hz. At the beginning of each block, a 9-point calibration was performed. Each trial began by requiring subjects to fixate on a central drift correction dot. After the eye-tracker registered a successful fixation, participants pressed the space bar to start the trial.

4.2.2.3 Procedure

Images were presented in three blocks, with 48 trials in each block. Images were shown individually in the center of the screen for five seconds each while eye-gaze was tracked. Experimental design consisted of three blocked conditions where viewing instructions were varied for each (see Figure 4.1-B for summary of experimental conditions). In one condition, viewing was unrestricted (Free View), and in the two remaining condition viewing was restricted (Avoid Eyes, Avoid Mouth). At the start of each block, subjects were instructed to examine the faces while following one of the following three viewing instructions: 1) avoid the eyes ("Avoid Eyes" condition), 2) avoid the mouth ("Avoid Mouth"), or 3) view the images freely ("Free View"). Lastly, to insure the faces were being inspected in the "Avoid" conditions, subjects were told they might be asked to answer questions about the faces at the end of the experiment, though no actual post-experiment evaluation took place. Instruction order and image order were randomized.

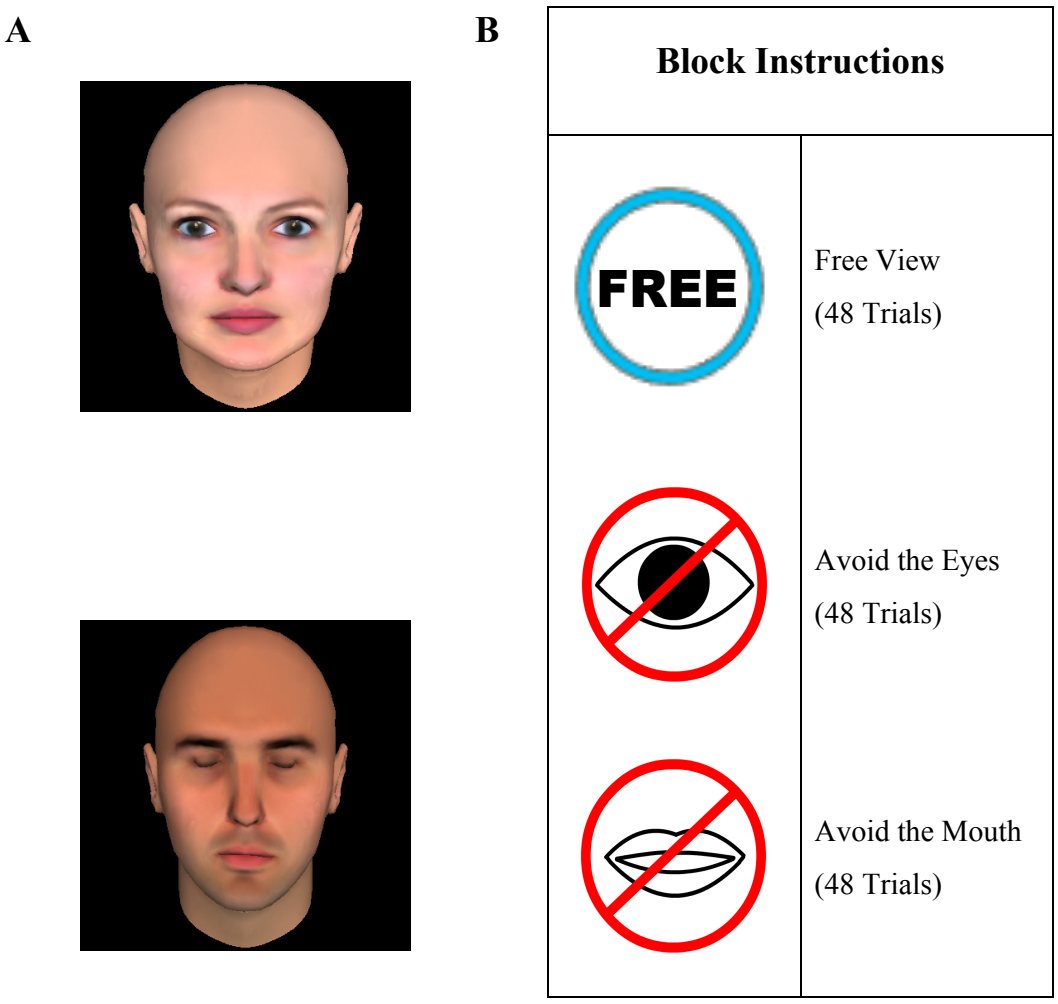


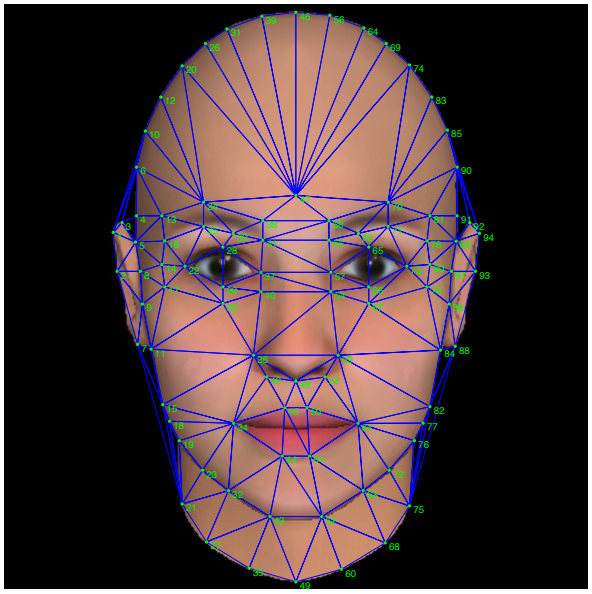
Figure 4.1. (A) Example stimuli showing Open Eyes (top) and Closed Eyes (bottom) faces, and (B) summary of experimental conditions.

4.2.2.4 Analyses

Data were analyzed using custom scripts written in Matlab. Trials in which more than 20% of eye-tracking data was missing (due to blinks and/or signal loss) were excluded from analyses (< 3% of trials). Raw eye-tracking data was pre-processed to extract fixation locations and durations. Fixations were defined as gaze points falling within 1 degree of visual angle for a minimum of 100 milliseconds.

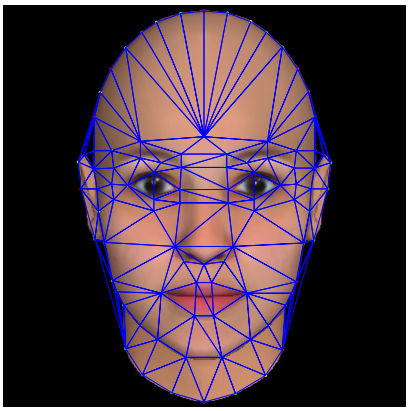
Because face stimuli differed in their locations of socially salient features, faces and the fixations on each face were normalized onto a template face using a morphing procedure (see Figure 4.2). Each face was manually labeled with 94 anatomical landmark points (including eyes, mouth, nose, and head outline), and transposed using Delaunay Triangulation onto identical points marked on a prototypical template face. Fixation locations were subsequently morphed from their locations on the stimulus face to the equivalent locations on the template face. All subsequent analyses were performed on these normalized fixations on the template face.

A



B

C



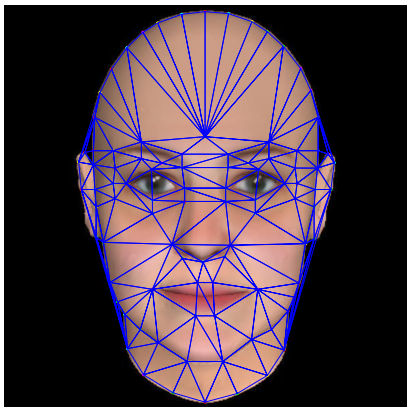


Figure 4.2. Morphing procedure to transpose fixations from all stimuli onto a prototypical template face. (A) Template face labeled with 94 anatomical landmark points. (B) Analogous points marked on the template face (left) and a stimulus face (right). (C) Triangulation used to transpose fixation locations from the stimulus face onto equivalent locations on the template.

To analyze gaze behavior, fixation heatmaps (or density maps) were calculated for each subject and condition by weighting fixation location by its duration, then spatially smoothing using a Gaussian kernel with sigma = 13, or 0.5 degrees of visual angle. Heatmaps were averaged across trials and subjects, and the resulting group maps were used for the ROI analyses described next.

We defined the following seven regions of interest (ROIs) on the template face: Left Eye, Right Eye, Eye Region Total, Nose, Mouth, Head Remainder, and Off-Head (see Figure 4.3 for a depiction of all regions on the template face). With the exception of Eye Region Total, which included Left Eye and Right Eye, ROIs were mutually exclusive. Designations for left and right eye are from the perspective of the viewer not anatomical.

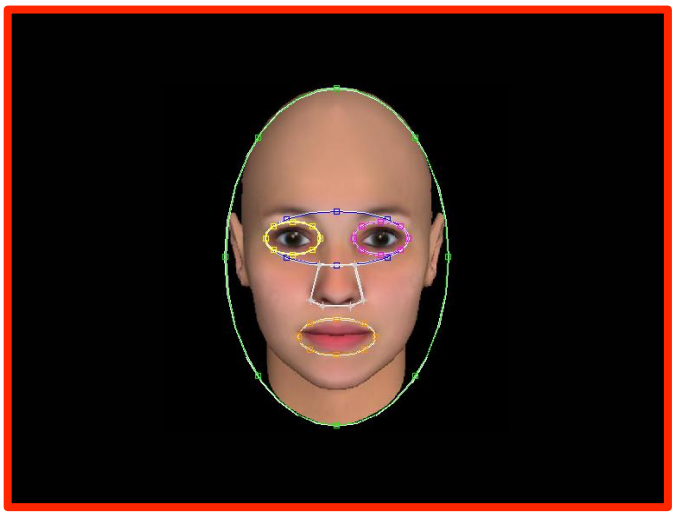


Figure 4.3. Template face with all regions of interest defined: yellow- left eye, magenta – right eye, blue – eye region total, gray – nose, orange – mouth, green – head remainder, red – off-head. With the exception of eye region total, which includes the left and right eyes, all regions were mutually exclusive.

We conducted three analyses examining the following: 1) the proportion of gaze in all ROIs, 2) the distribution of gaze when it was in the eye region, and 3) center bias in the eye and mouth regions. Each analysis used a different subset of ROIs (see Figure 4.4).

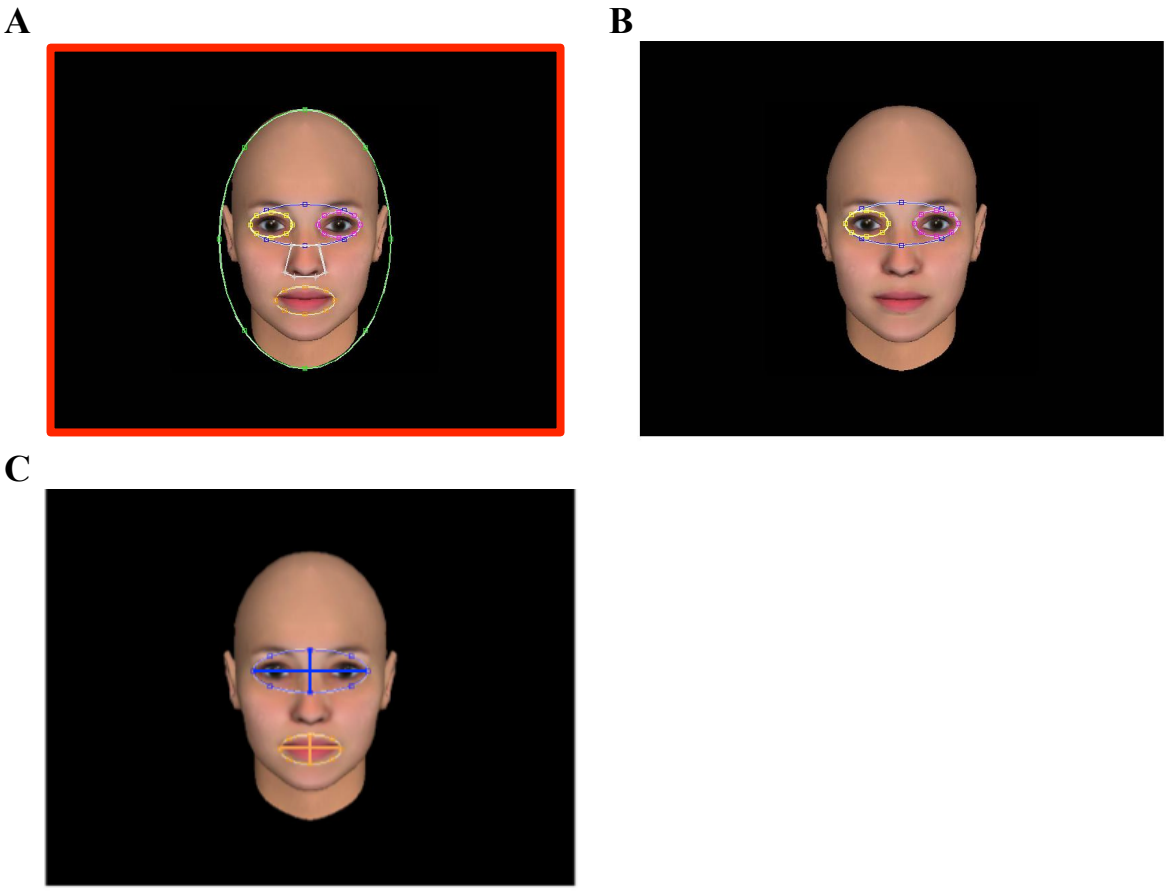


Figure 4.4. ROI configurations used for the various analyses. (A) Gaze proportions to all regions of interest, (B) Gaze proportion to the eye region only, (C) Center Bias – average distance to the horizontal and vertical midlines.

For the first analysis examining gaze to all ROIs, we calculated the proportion of gaze time in each of the seven regions, summing the density map in each ROI then dividing by the sum of the entire on-screen density map.

Given that total gaze to the eye region might be diminished in ASD, we then conducted a second analysis comparing where gaze was distributed only in the eye-related ROIs (Left Eye, Right Eye, and the remainder of the Eye Region ellipse), calculating the proportion of time in each relative to total gaze in the eye region only (i.e., Eye Region Total) rather than total gaze on-screen. This analysis would indicate whether the distribution of gaze among the three eye-related ROIs differed between groups.

Finally, for the analysis of center bias, we analyzed the two ROIs defining the socially salient regions of the face (Eye Region Total and Mouth). For the Eye and Mouth ROIs, we calculated the Euclidean distance for each point within the ROI to the vertical and horizontal midlines of the ROI, weighting each distance by gaze duration (i.e., the heatmap value for the point). Next, we summed these values, and then divided by the sum of gaze in the ROI to obtain the average gaze distance to the horizontal and vertical midlines.

Statistical analyses were conducted by carrying out repeated-measures ANOVAs for each ROI in the analysis subset, with a between-subjects factor of group (ASD, Control) and within-subjects factors of condition (Free View, Avoid Eyes, Avoid Mouth) and stimulus type (Open Eyes, Closed Eyes). In order to investigate the relationship of the two restricted conditions (Avoid Eyes, Avoid Mouth) against the unrestricted condition (Free View), appropriate contrasts were also conducted for gaze to the Right Eye, Left Eye, Eye Region Total, and Mouth. Lastly, we calculated Pearson correlations between AQ and proportion of gaze to ROIs across all subjects, and ADOS-CSS-Overall scores and proportion of gaze to ROIs for the autism subjects only.

4.2.3 Results

Heat maps for ASD subjects and control subjects in all three conditions are shown below in Figure 4.5.

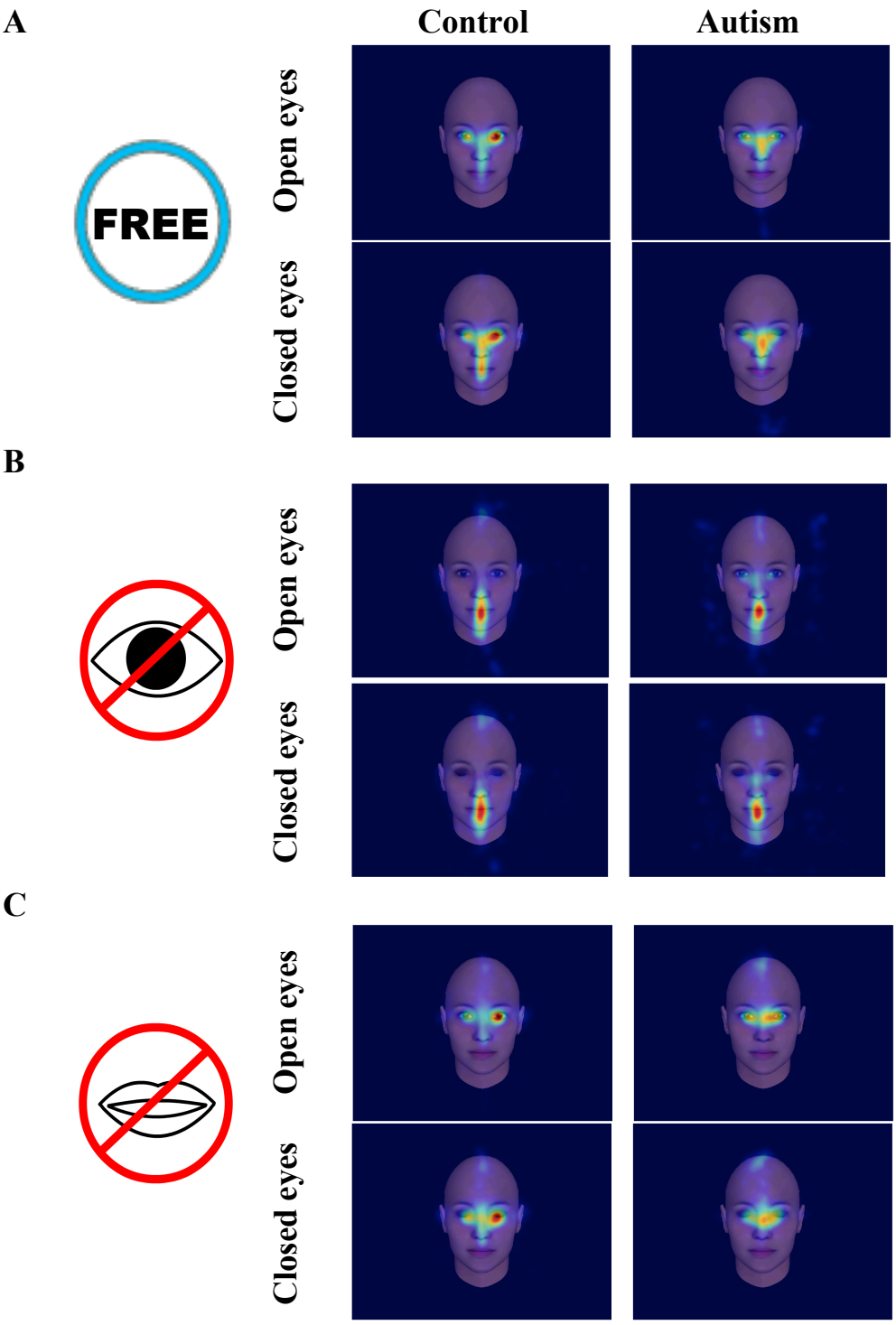


Figure 4.5. Heat maps for the Autism and Control groups, and condition with Open Eyes and Closed Eyes stimuli. Maps were generated by using a Gaussian kernel

function to spatially smooth each duration-weighted fixation point, then maps were averaged across trials and subjects. Warmer colors represent longer total fixation time.

4.2.3.1 Gaze proportions in all regions of interest

The first set of analyses focused on gaze to the different regions of interest (see Figure 4.4-A for ROIs). A repeated-measures ANOVA with between-subjects factor of group and within-subjects factors of condition and stimulus was conducted for each of the seven ROIs (see Figure 4.6).

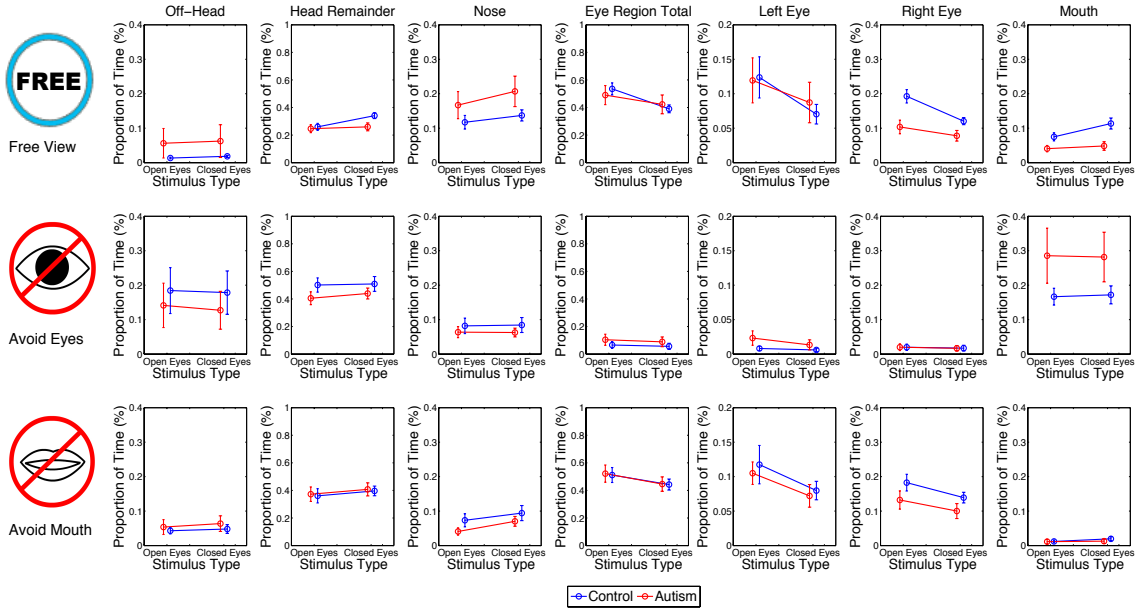


Figure 4.6. Proportion of fixation time in the ROIs in the ASD (red) and control (blue) groups. Error bars denote standard error.

Right Eye

The ANOVA for the right eye revealed a significant main effect of group on gaze time, $F(1,23) = 5.56$, $p = .027$, $\eta^2 = .195$. Overall, ASD looked less at the right eye than Controls regardless of stimulus type or condition (ASD: $M = 7.7\%$, $SE = 1.1$; Controls: $M = 11.4\%$, $SE = 1.1$). While the interaction between group and stimulus did not reach significance, $F(1,23) = 2.77$, p

= .109, η^2 = .108, the effect size indicates there is likely a greater sensitivity of stimulus type on Controls than ASD, such that the decrease in gaze between open and closed eyes is larger in the Control group than the ASD group (ASD: 2.1%; Controls: 4.0%).

There was also a marginally significant interaction between condition and group, $F(1.59,36.61) = 2.86$, $p = .081$, $\eta^2 = .111$. A planned contrast comparing the unrestricted condition to Avoid Eyes and Avoid Mouth indicated there was a significant interaction between condition and group for Avoid Eyes – Free View, $F(1,23) = 10.78$, $p = .003$, $\eta^2 = .319$, but not for Avoid Mouth – Free View, $F(1,23) = 0.42$, $p = .521$, $\eta^2 = .018$. While Controls looked more to the right eye than ASD in the Free View condition (ASD: $M = 9.3\%$, $SE = 1.6$; Controls: $M = 15.5\%$, $SE = 1.5$; $t(23) = 3.05$, $p = .006$), there was no group difference in "Avoid Eyes," ($p = .992$).

Left Eye

The ANOVA for the left eye revealed no significant interactions involving group (all ps > .627), nor a main effect of group ($p = .228$).

Eye Region Total

The ANOVA for the total eye region revealed no significant interactions involving group (all ps > .309), and no main effect of group ($p = .783$).

Mouth

The ANOVA for the mouth region indicated there was a marginally significant interaction between group and condition, $F(1.08,25.03) = 3.58$, $p = .067$, $\eta^2 = .135$. There was also a marginally significant interaction between group and stimulus, $F(1,23) = 3.36$, $p = .080$, $\eta^2 = .127$, suggesting a greater influence of stimulus type on gaze to the mouth in Controls than ASD . There was not a significant main effect of group ($p = .473$).

Contrasts comparing the unrestricted condition to Avoid Eyes and Avoid Mouth revealed a significant interaction between group and condition for both Avoid Eyes – Free View, $F(1,23) = 4.90$, $p = .037$, $\eta^2 = .176$, and Avoid Mouth – Free View, $F(1,23) = 5.93$, $p = .023$, $\eta^2 = .205$. Both effects were driven by a significant group difference in the Free View condition, with

ASD looking less at the mouth than Controls (ASD: M = 4.5%, SE = 1.0; Controls: M = 9.6%, SE = 1.0; $t(23) = 3.05$, $p = .006$), but no group differences in either of the other two conditions (ps > .153). In other words, while ASD looked less at the mouth in Free View than Controls, both groups significantly increased gaze to the mouth in the Avoid Eyes condition and decreased gaze to the mouth in the Avoid Mouth condition relative to Free View.

Nose

The ANOVA for gaze to the nose revealed a marginally significant interaction between group and condition $F(2,46) = 3.19$, $p = .074$, $\eta^2 = .122$. There were no other significant interactions involving group (all ps > .381) and no main effect of group ($p = .871$).

The contrast comparing Free View to Avoid Mouth revealed a significant interaction between group and condition, $F(1,23) = 5.41$, $p = .029$, $\eta^2 = .190$, indicating that the ASD group looked more at the nose than Controls in Free View, (ASD: M = 18.7%, SE = 4.1; Controls: M = 12.7%, SE = 1.7) but less than Controls in Avoid Mouth (ASD: M = 5.6%, SE = 1.1; Controls: M = 8.4%, SE = 2.0). Both Controls and ASD also decreased gaze to the nose region in the Avoid Mouth condition compared to Free View, but that decrease was greater in ASD.

Head Remainder

The ANOVA for the head remainder revealed no significant interaction effects involving group (all ps > .327), and no main effect of group ($p = .343$).

Off-Head

The ANOVA for gaze off-head revealed no significant interaction effects involving group (all ps > .438), and no main effect of group ($p = .934$).

4.2.3.2 AQ and ADOS correlations with gaze to ROIs

AQ Correlations Across Groups

In the Free View condition, AQ was negatively correlated with gaze to the right eye for Open Eyes stimuli (r = -.459, n = 25, $p = .021$), and gaze to the mouth for Closed Eyes stimuli (r = -.463, n = 25, $p = .020$). Also, in Free View there was a negative correlation with gaze to the

Head Remainder for Closed Eyes stimuli (r = -.401, n = 25, p = .047). In the Avoid Eyes condition, AQ was positively correlated with gaze to the left eye for Open Eyes stimuli (r = .460, n = 25 p = .021). No correlations were significant in the Avoid Mouth condition.

ADOS CSS-Overall Correlations in Autism Group

In the Avoid Mouth condition, there was a negative correlation between ADOS severity scores and gaze to the right eye for Open Eyes stimuli (r = -.681, n = 11, p = .021), as well as a correlation for gaze off-head, for both Open Eyes stimuli (r = .670, n = 11, p = .024), and Closed Eyes stimuli (r = .664, n = 11, p = .026). Also in Avoid Mouth, there was a positive correlation for gaze to the head remainder for Open Eyes stimuli, (r = .615, n = 11, p = .044), and a negative correlation with gaze to the nose for Closed Eyes stimuli (r = -.679, n = 11, p = .022). None of the remaining correlations reached significance in any of the conditions.

4.2.3.3 Gaze distribution in eye region

To examine the distribution of gaze in the eye region, we calculated the proportion of gaze time in each eye ROI relative to the total gaze time spent in the entire eye region (see Figure 4.4-B for ROIs). Results are summarized in Figure 4.7.

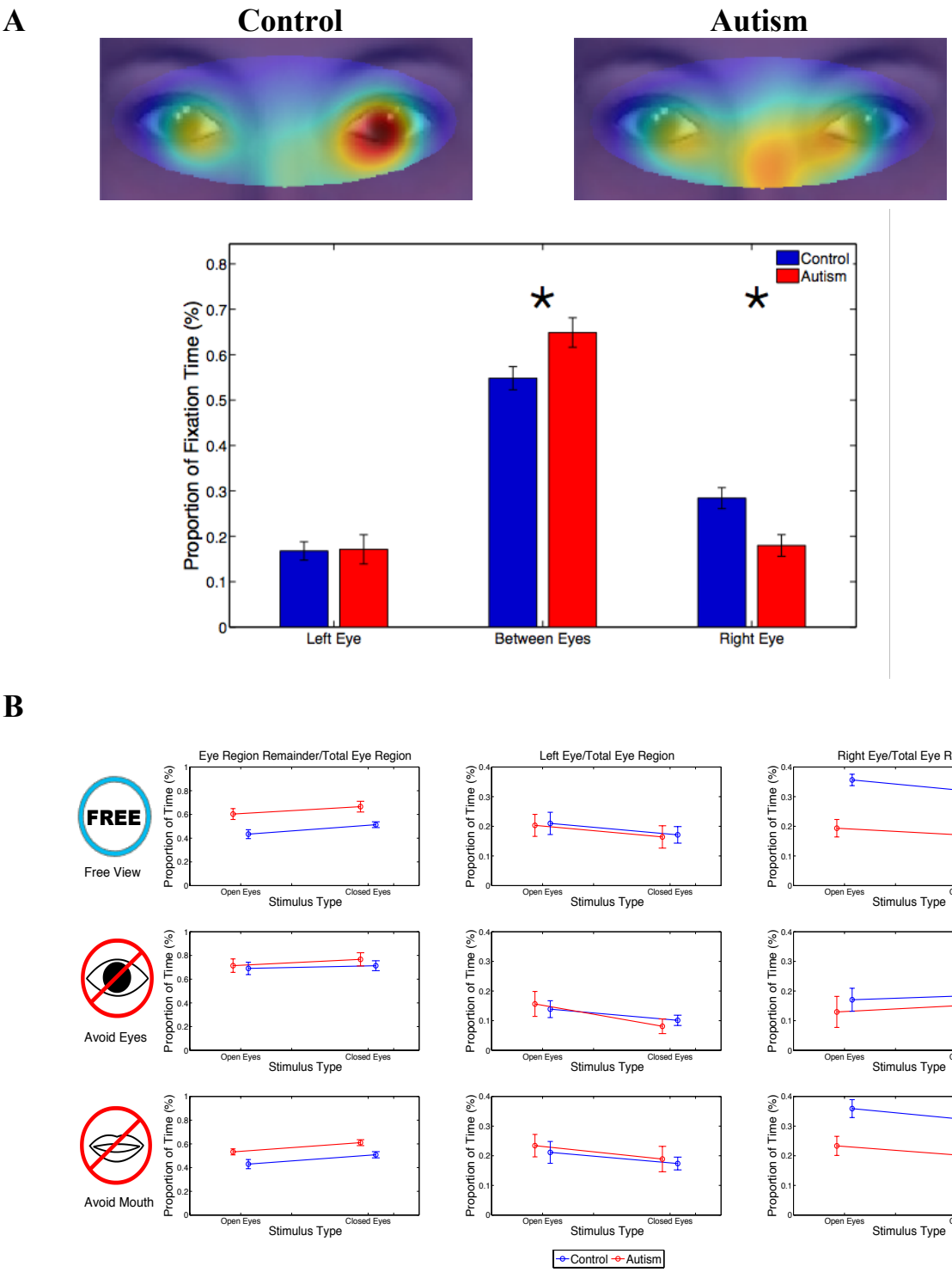


Figure 4.7. (A) Heatmaps and gaze proportions in the eye-related ROIs in the ASD (red) and control (blue) groups collapsed across condition and stimulus type. (B) Gaze

proportions in the eye-related ROIs in the ASD (red) and control (blue) groups divided by condition and stimulus type. Error bars denote standard error.

Right Eye

The ANOVA for the right eye revealed a marginally significant interaction between group and condition, $F(2,22) = 3.09$, $p = .066$, $\eta^2 = .219$. There was also a significant main effect of group, $F(1,23) = 9.07$, $p = .006$, $\eta^2 = .283$, indicating the ASD group spent a significantly smaller proportion of gaze to the eye region fixating on the right eye relative to Controls, regardless of condition (ASD: $M = 18.0\%$, $SE = 2.5$; Controls: $M = 28.4\%$, $SE = 2.4$).

Planned contrasts comparing the unrestricted condition to the two restricted conditions revealed that there was a significant interaction between group and condition in Avoid Eyes – Free View, $F(1,23) = 6.45$, $p = .018$, $\eta^2 = .219$, indicating the ASD group spent a smaller proportion of time in the eye region looking at the right eye in Free View (ASD: $M = 18.2\%$, $SE = 2.8$; Controls: $M = 33.6\%$, $SE = 1.9$; $t(23) = 3.52$, $p < .001$) but not in Avoid Eyes, $p = .507$.

Left Eye

The ANOVA for the left eye revealed no significant interactions involving group (all ps > .448) and no main effect of group ($p = .927$).

Eye Region Remainder

The ANOVA for the remainder of the eye region revealed no significant interactions involving group (all ps > .168). There was, however, a significant main effect of group, $F(1,23) = 5.54$, $p = .027$, $\eta^2 = .194$, indicating that the ASD group spent a greater proportion of their gaze in the eye region fixating between the eyes (ASD: $M = 64.9\%$, $SE = 3.1$; Controls: $M = 54.8\%$, $SE = 3.0$).

4.2.3.4 Center bias to horizontal and vertical midlines

To compare average gaze distance (measured in degrees of visual angle) from the vertical and horizontal midlines in the socially salient regions of the face, we conducted two repeated-measures ANOVAs for the Eye Region and Mouth ROIs (see Figure 4.4-C for ROIs).

Eye Region

The ANOVA for the eye region revealed a main effect of group for distance to the vertical midline, $F(1,23) = 5.89$, $p = .024$, $\eta^2 = .204$, indicating the average horizontal distance to the midline was significantly less in the ASD group relative to the Control group (ASD: $M = 1.49$ dva, $SE = .08$; Controls: $M = 1.75$ dva, $SE = .07$). Center bias for gaze to the vertical midline in the eye region is shown in Figure 4.8.

There were no significant interactions involving group for distance to the horizontal midline (all ps > .497). There was, however, a marginally significant effect of group, $F(1,23) = 3.32$, $p = .081$, $\eta^2 = .126$, for greater vertical distance to the midline in the ASD group (ASD: $M = .84$ dva, $SE = .03$; Controls: $M = .77$ dva, $SE = .03$).

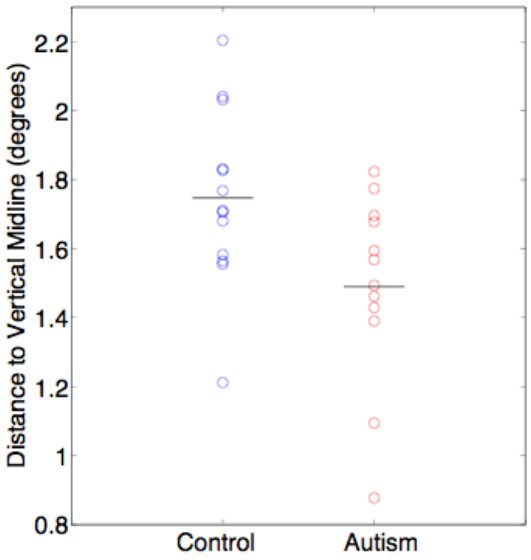


Figure 4.8. Mean distance to the vertical midline in the Eye Region, collapsed across stimulus type and condition. Distance is measured in degrees of visual angle. Dots represent individual subjects and solid lines denote group mean.

Mouth

The ANOVA for the mouth did not reveal any significant interactions involving group for distance to the vertical midline (all *p*s > .291), nor a main effect of group ($p = .799$). There were also no significant interactions involving group for distance to the horizontal midline (all *p*s > .737), nor a main effect of group ($p = .970$).

4.2.4 Discussion

In this study, we investigated one of the basic building blocks of social processing, face scanning, to examine atypical face gaze in high-functioning autism as well as the flexibility of atypical fixation behavior. We found differences between groups in the details of the gaze pattern, though gaze to some of the general regions were similar, as well differences in how the ASD group updated face scanning strategies in response to ROI restrictions. We found that people with ASD exhibit a similar pattern of gaze to the face and off the face as controls, showing a preference for examining the face over non-face areas of the screen, and when looking at the face, favoring the most socially salient part, the general eye region. Both groups also performed equally well in avoiding the eyes and mouth in the Avoid Eyes and Avoid Mouth conditions, respectively. Similar to the controls' gaze behavior, when the eyes were to be avoided, the ASD group also increased gaze to the mouth, indicating that the ASD group recognized the significance of looking to these two regions for information, whether or not there is difficulty in subsequently processing that information. There were two key differences in the details of gaze distribution to the face however: first, the ASD group demonstrated a significant center bias when looking to the eye region, spending more time looking *between* the eyes and less time looking at the right eye than controls. Second, the ASD group also spent significantly less time than controls looking at the mouth.

In contrast to studies that have reported avoidance of or reduced direct eye contact (Boraston, Corden, Miles, Skuse, & Blakemore, 2007; Kliemann et al., 2010), we found that for both faces with open eyes and faces with closed eyes, the proportion of gaze time spent in the eye region did not differ between ASD and controls, and people with ASD did not significantly change gaze to the eye region between open-eyed and closed-eyes faces, indicating that there was no avoidance of the eye region, nor an avoidance of direct gaze.

It is important to note, however, that there are hints of a differential effect of stimulus type on the two groups, supported by two marginally significant interactions (between group and stimulus) for the right eye and mouth ROIs. These interactions suggest that the ASD group maintains their gaze to the eye and mouth regions in similar proportions regardless of stimulus type, whereas controls decrease gaze to the right eye and increase gaze to the mouth when the eyes are closed compared to open. The suggestion of reduced sensitivity to the type of social stimuli is further supported by the negative correlations between AQ and gaze to eyes and mouth in the Free View condition, for open eyes and closed eyes stimuli respectively. The controls seem to recognize the diminished social significance of closed eyes relative to open eyes, and adjust gaze behavior accordingly, shifting gaze to gather information from the next most socially-salient feature of the face. The absence of a comparable gaze shift in ASD coupled with otherwise normal proportions of gaze to the eye region implies that there is relatively invariable gaze behavior with a failure to update viewing strategy in response to changes in information in the eye region. The results also provide support for the idea that atypical gaze could be driven by *diminished sensitivity* to the quality of information in the eye region rather than an avoidance of direct gaze, or aversion to the eye region in general.

This interpretation is consistent with previous studies that report diminished significance of visual social cues due to amygdala hypo-arousal (Senju & Johnson, 2009) rather than a hyper-arousal/aversion account (Dalton et al., 2005). It is known that gaze to the eyes is associated with amygdala activation in neurotypicals (Adolphs et al., 1998; Schultz, 2005; Whalen et al., 2004). The hyper-arousal model proposes that direct gaze is aversive to people with autism, perhaps due to hyper-activation in the amygdala in response to eye contact, and therefore diminished eye contact is an adaptive response meant to alleviate that discomfort. The model would predict then that people with autism would actively avoid eye gaze, and also demonstrate greater avoidance of direct gaze relative to indirect gaze or closed eyes. On the other hand, the *hypo*-arousal claims there is under-activation in the amygdala in response to eye contact, the result of which is reduced reward value and saliency of the eyes. The latter model would predict a reduced preference for rather than an active aversion of the eyes, and no difference in response to direct gaze and indirect gaze or closed eyes. In line with the hypo-arousal model for ASD, our results showed relatively normal gaze to the eye region in the

conditions in which eye gaze was permissible, indicating there was virtually no avoidance of the eye region or of direct gaze. However, there was also little shifting of gaze to the mouth and eye regions based on stimulus type, suggesting that people with ASD had difficulty perceiving there was diminished quality of information with closed eyes.

Interestingly, there was little difference between groups in the proportion of on-screen gaze devoted to the total eye region and to the left and right eye combined, but in comparing the left and right eye separately there were two notable differences. First, the ASD group distributes gaze evenly between the left and right eye, whereas controls show a significant bias for the right eye over the left eye. Second, the ASD group looks significantly less to the right eye than controls regardless of stimulus type and condition. The discrepancy in interest in the right eye is further underscored by the finding that, while controls favored the right eye more than any other facial feature in Free View (followed by the nose, left eye, then mouth), people with ASD showed an unusually strong preference for a different facial feature, the nose, looking at it twice as long as the right eye (and four times as long as the mouth).

When people with ASD looked at the eye region, the distribution of gaze time in the three eye-related ROIs (left eye, right eye, remainder of eye ellipse) also revealed differences in eye gaze strategy. An analysis comparing the relative distribution of gaze amongst the three regions, i.e., dividing gaze in each eye-related ROI by total gaze in the eye region, rather than by total gaze on-screen, confirmed there were differences in gaze to the right eye and to the eye region remainder. First, the reduced interest to the right eye was maintained even after accounting for total time spent in the eye region, which was not surprising given the relatively comparable gaze time spent in the total eye region between the two groups. The lack of right eye bias is consistent with findings from a recent study (Yi et al., 2013) which reported significantly less gaze to the right eye in children with ASD compared to controls. Second and more strikingly, there was a significant difference in gaze to the remainder of the eye region, which consists largely of the region in between the eyes. Compared to the controls, the ASD group devoted a greater proportion of gaze time in the eye region looking *between* the eyes, regardless of stimulus type or condition. Our results demonstrate a lateralization of gaze to the eye region in controls that is absent in people with ASD.

Our analysis of center bias in the eye region revealed a tendency for people with ASD to look closer to the vertical midline in the eye region, but further away from the horizontal midline than controls. Behaviorally, this amounts to participants with ASD looking above and below the pupil region rather than looking directly at the pupil, and looking between the eyes rather than lateralizing gaze to either eye (also supported by the results of our analyses above). The center bias in ASD together with a reduced reliance on the right eye demonstrates a diminished tendency for the ASD group to maximize perception of social information by lateralizing gaze to the eye region when eye gaze is allowed. The results from our study are consistent with findings from an unpublished study (Wang et al., in preparation) that found people with ASD had a stronger bias toward the center of images, which they suggest could be attributable to a combination of factors, including slower saccade velocity and reduced saliency perception of faces and social cues.

Gaze to the mouth also differed between groups in the unrestricted condition. Though the ASD group did explore the mouth region in the unrestricted condition, they did so significantly less than controls. Decreased gaze to the mouth contrasts with some studies reporting increased reliance on the mouth in ASD (Klin et al., 2002; Neumann et al., 2006; Spezio et al., 2007), but is consistent with others that have found reduced gaze to the mouth (Pelphrey et al., 2002). Our results showing diminished mouth gaze in the unrestricted condition could be due to the use of static stimuli, which might result in reduced saliency of the mouth relative to dynamic stimuli (Irwin & Brancazio, 2014; Senju & Johnson, 2009).

There was also a striking difference in gaze to the mouth in the Avoid Eyes condition relative to Free View. In contrast to the minimal mouth gaze observed in Free View, the ASD group significantly increased mouth gaze when instructed to avoid the eyes, spending nearly a third of their gaze time in this region. Furthermore, while gaze to the eyes and nose was equivalent between groups for the Avoid Eyes condition, the ASD group spent more time on the mouth than controls in this condition, whereas controls explored the head and face remainder more than ASD. While controls did increase gaze to the mouth, they did so less drastically, continuing instead to explore the face by also increasing gaze to the remainder of the face.

The substantial bias toward the mouth appears to be driven by a strict adherence to the Avoid Eyes instruction rather than a gaze shift driven by inherent saliency of the mouth or an updated strategy to continue exploring the face for information: that the ASD group originally showed little interest in the mouth in Free View makes it highly unlikely that they originally perceived the mouth as the next most informative feature. Furthermore, the notable decrease in nose gaze between Free View and Avoid Eyes signifies the ASD group did not rely upon the feature they found so salient in the unrestricted condition. This points to the use of a new strategy rather than an updating of the strategy used in Free View, one that involves avoidance of the eye region and the regions near it by fixating on the mouth at the expense of exploring the face.

In the Avoid Mouth condition, the ASD group adhered to the ROI restriction by avoiding the mouth and regions near it. People with ASD deviated from the scanning approach they used in Free View, spending significantly less time on the nose region than they had in the unrestricted condition, whereas controls generally returned to the behavior they demonstrated in the unrestricted condition with the exception of avoiding the mouth. Moreover, correlations with ADOS severity scores suggest there may be different viewing strategies in ASD associated with the severity of impairment. First, high-scoring participants spent less time on the nose of closed-eyes stimuli and more time looking off the head for both stimuli, which indicates high-scoring participants make greater changes to their behavior relative to the unrestricted condition. Furthermore, it is important to note that these changes do not appear to be socially adaptive, given the positive correlation with off-head gaze. Second, while high-scoring subjects were more likely to look at the remainder of the face, they also looked less at the right eye of open-eyed stimuli. In other words, high-scoring subjects were less likely to attend to the most salient feature of the face, even though they were not instructed to avoid it in this condition.

If face scanning strategies remained similar in the restricted conditions to the ones used in Free View, gaze to the facial features typically relied upon for social cues would change very little with the exception of the restricted ROI. The scanning approach adopted by controls when instructed to avoid the eyes or mouth demonstrates a flexible ability to update viewing

strategies to accommodate ROI restrictions, while also continuing to explore the face. The ASD group, on the other hand, appears to have difficulty adapting the approach they used in Free View, instead changing their strategy for each condition. In the Avoid Eyes condition, the ASD group fixates on the mouth at the expense of exploring the rest of the face and in the Avoid Mouth condition the ASD group also avoids the nose even though they relied upon it heavily in the unrestricted condition.

There are several (potentially interdependent) factors that could contribute to the group differences in viewing strategy. One explanation for the differences in gaze behavior might be that the approach used by the ASD group in the unrestricted condition could not be easily adapted to the ROI restricted condition if it relied heavily on gaze between the eyes and on the nose, which is indeed consistent with our findings. A second possibility is that exploring the face for social information might not be a natural, spontaneous tendency in ASD, but instead requires top-down engagement that is otherwise being utilized in the restricted conditions to avoid specified face features. The possibility of diminished automatic face exploration would also be in line with our observations of a center bias in the eye region, reduced face exploration in the Avoid Eyes condition, and the change in strategy in the Avoid Mouth condition.

With regard to the significant change in mouth gaze between conditions, it may be the case that looking at the eyes, mouth, and nose is part of a rule-based strategy for salient features that becomes imbalanced when instructed to avoid the eyes, the region to which people with ASD may normally try to attend to the most. People with autism may also inhibit a tendency to naturally fixate on the mouth in the Free View condition by focusing on the eye region. When the eyes must be avoided, the propensity for mouth gaze could become more apparent, possibly due to the high cognitive load experienced in an atypical social gaze task such as the one in the present study. This interpretation would be consistent with reports of people with ASD demonstrating greater face processing impairments in more cognitively demanding tasks, but less so in simpler tasks (Baron-Cohen et al., 1997; Evers, Kerkhof, Steyaert, Noens, & Wagemans, 2014; Klin et al., 2002).

The lack of a right eye bias in ASD suggests that people with autism are less responsive to the differences in quality and/or quantity of social information communicated by the two sides of the face. One theory that has been suggested for why controls show a right eye bias is that it is associated with the greater emotional expressivity communicated by the left hemiface, or right side of the face from the observer's perspective (Powell & Schirillo, 2009). Indeed, studies have demonstrated that the left hemiface is more involved in the expression of facial emotion, expressing emotions (and negative ones in particular) more intensely than the left side of the face (Borod, Haywood, & Koff, 1997; Sackeim, Gur, & Saucy, 1978). In this respect, that the ASD group does not show a right eye bias suggests there is impairment in responding to the difference in expressivity. One question that remains to be answered, however, is at what stage of perception and processing the impairment might occur. One can imagine at least two possibilities: one, that people with ASD have difficulties perceiving any difference in expressivity in the first place, or two, that the impairment is not in perception of the information but rather what to do with it. In other words, people with ASD may recognize that there is a difference in the quality of social information conveyed by the halves of the face, but have difficulty processing that information and relating it to social precepts, and as such, do not show a preference for the right side of the face.

Moreover, our findings suggest that part of the atypical viewing strategy in ASD consists of fixating on the region between the eyes and on the nose, a strategy that can easily impart an impression of neurotypical gaze behavior in social interactions, as well as in certain experimental settings. The underlying source of this gaze behavior is unclear, but a variety of influencing factors can be assumed. One possibility is that subjects may have participated in interventional therapies for improving social skills (Faja, Aylward, Bernier, & Dawson, 2007; Tanaka et al., 2010; Rao, Beidel, & Murray, 2008), which teach people with autism to look between the eyes during social interactions to improve the quality of face-to-face interactions. Another possibility is that gaze between the eyes is a learned behavior (either implicit or explicit) that individuals with autism have learned can approximate normal social behavior, and additionally, may even help processing of social cues. Several studies have demonstrated that high-functioning individuals are able to develop or adopt compensatory strategies to improve social skills (Bauminger, 2002; Yirmiya, Pilowsky, & Solomonica-Levi, 1999). Though these

strategies are often not as flexible or adaptive in situations that are unusual or require high cognitive effort, they are often sufficient for many other day-to-day situations.

Our results indicate that in the two restricted conditions, people in the ASD group were significantly impaired in their ability to simultaneously adhere to the ROI restriction and also update gaze behavior to continue exploring the face. The difficulty in adapting gaze behavior could very well be associated with published reports of deficits in the domains of cognitive flexibility and cognitive switching, perhaps due to difficulty integrating and using new information (Geurts, Corbett, & Solomon, 2009; Hill, 2004). One consequence of the impairment is the restricted and repetitive behaviors that are a characteristic feature of autism. Cognitive rigidity is observed in a variety of behavior, from a preoccupation with specific, limited interests (and objects), to perseveration in rituals, routines, and motor movements. Another notable outcome of this inflexbility is that people with ASD have difficulty updating behavioral strategies to adapt to new social situations and cues. That is not to say that the ability to adapt is absent, but rather impaired or inflexible, such that they have difficulty interpreting and responding appropriately to the shifting contextual demands of a social interaction. People with autism are known to compensate for some of these impairments using compensatory behavioral and processing strategies (Kasari, Chamberlain, & Bauminger, 2001; Plaisted, Swettenham, & Rees, 1999; Rosset et al., 2008; Sigman & Ruskin, 1999; Teunisse & Gelder, 1994).

Closely related to the putative difficulty updating behavioral strategies, another explanation for the diminished updating of face scanning strategies could be what has been called "enhanced logical consistency" in autism (De Martino, Harrison, Knafo, Bird, & Dolan, 2008). The results of De Martino's study suggested people with ASD to show reduced integration of emotional and social information into decision-making processes, relying instead on more logical, rational patterns of decision-making. While our task did not involve decision-making, it did involve coordinating social behavior to task instruction, which involves an element of (implicit or explicit) decision-making and therefore is susceptible to a decision-making bias, during which people with ASD may fail to incorporate social and emotional cues into their viewing strategy. Instead, people with autism may have become task-focused, and prioritized

adhering to the task restrictions. In this sense, "succeeding" at the task of avoiding salient regions also may come at the cost of reduced behavioral flexibility.

We can draw two over-arching conclusions from the results of the present study. First, the group differences in viewing strategy in response to task demands and social stimuli highlight the flexible updating of viewing strategies in controls, which aim to maximize the amount of social information gathered. Our findings of a center bias toward the eyes and increased fixation on the nose indicate this tendency is compromised in ASD. Second, our results also demonstrate that viewing strategies in ASD are less flexible and adaptive than controls', particularly in a changing social context. Our findings of reduced face exploration in the restricted conditions and significant deviation from the strategy used in the unrestricted condition by people with ASD support this conclusion. In sum, it appears that the ability of people with ASD to adjust and update viewing strategies is impaired, whereas controls demonstrate greater flexibility by exploring the face while avoiding the specified regions. These findings demonstrate a possible approach for assessing social functioning skills in a manner that circumvents the use of compensatory strategies, and which requires them to adapt to new situations, reflecting the challenges experienced in daily social functioning.

Our findings suggest some clear future directions. First, gaze behavior in the Avoid Mouth condition was more similar between groups than in Free View, though what conclusions can be drawn from this are uncertain at the moment. Given the known heterogeneity in ASD, there are likely sub-types of individuals that exhibit similar behavior, as well as individual variations in behavior, that are obfuscated in a group level analysis. While the sample size in the present study was too small to examine possible ASD sub-types, future studies should investigate whether there are distinct cognitive profiles in ASD that could be characterized by measures of flexibility in viewing behavior. Second, people with ASD, particularly those who are high-functioning, may respond differently to dynamic stimuli compared to the static stimuli we used in the present study, or to stimuli that require great cognitive effort to process. Pilot results from our research group indicate face gaze impairments might be more pronounced in live social interaction (Wang, Shimojo, & S. Shimojo, 2015). Future studies using dynamic face

stimuli and more complex social stimuli will be important in understanding the specific contexts in which social impairments occur in high-functioning autism.

In summary, while the general gaze patterns to regions of the face appeared similar, there were functional and qualitative differences in the details of how the ASD group looked at faces in in the unrestricted condition and how they adjusted gaze in the restricted conditions. People with autism demonstrated a clear bias for looking between the eyes and showed a tendency for reduced sensitivity to the right eye. Furthermore, when a condition was imposed to avoid certain facial features, people with ASD demonstrate rigidity in gaze behavior that adhered to the ROI restriction but at the cost of extensive exploration of the face, suggesting that people with autism have difficulty updating pre-existing face scanning strategies in changing social contexts.

4.3 Don't Look Study in Amygdala Lesion Patients

4.3.1 Materials and methods

4.3.1.1 Participants

AP, AM, and BG are three female participants with bilateral amygdala lesions caused by Urbach-Wiethe disease (M_{age} = 35.3 years, *SD* = 6.4, age range = 28-39). Two of the participants, AM and BG, are monozygotic twins. Anatomical scans of the lesions for the three participants can be seen in the Methods section of the Gaze Cascade study in amygdala lesion patients (section 3.3.1.1 Participants).

The comparison group consisted of 3 healthy female controls (M_{age} = 30.3 years, *SD* = 7.1, age range = 24-38), group-matched for age and IQ, with no family history of psychiatric illness. Two of the controls were the same controls tested for the Gaze Cascade study in amygdala lesion patients. All participants also completed the Autism Spectrum Quotient scale, or AQ (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001). Table 4.2 summarizes demographic and diagnostic information for participants.

Table 4.2. Demographic information for amygdala lesion and control participants in the Don't Look study.

	Amygdala group			
	Age	*Verbal IQ*	*Full scale IQ*	*AQ*
AP	28	92	98	20
AM	39	94	96	21
BG	39	99	101	18
Mean	34.3	95.0	98.3	
SD	6.4	3.6	2.5	
	Control group			
	Age	*Verbal IQ*	*Full scale IQ*	*AQ*
1	24	95	100	11
2	29	116	116	9
3	38	104	102	11
Mean	30.3	105.0	106.0	
SD	7.1	10.5	8.7	

a. Verbal IQ and full-scale IQ from the Wechsler Abbreviated Scale of Intelligence; AQ: Autism Quotient.

Independent samples t-tests showed that the groups did not significantly differ in terms of age ($t(4) = -0.73$, $p = .507$) and IQ ($t(4) = 1.46$, $p = .217$), as measured by the Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999) or the German-language adaptation. All participants gave written informed consent to participate under a protocol approved by the Institutional Review Board of the California Institute of Technology.

4.3.1.2 Stimuli and apparatus

Stimuli and apparatus were identical to those described in the Methods section of the Don't Look study in autism participants (see section 4.2.2.2 Stimuli and apparatus). They are described again here only for convenience.

Stimuli consisted of 144 computer-generated male and female faces, created with Facegen (Singular Inversions, Vancouver, Canada). Faces were front-facing with a neutral emotional expression (see Figure 4.9-A for sample stimuli). Half of the faces shown depicted open eyes and direct eye contact, and the other half depicted closed eyes. Each block had an equal number of faces with open eyes and closed eyes, and an equal number of male and female faces. No faces were repeated.

Images were presented on a 21" CRT monitor with a refresh rate of 100 Hz and pixel resolution of 1152 x 870. The stimuli were shown individually in the center of the screen for five seconds. At a viewing distance of approximately 52 cm, each face stimulus had an overall size of 22.9 (width) x 22.9 (height) degrees of visual angle.

Stimuli were presented using Matlab 2010a (Mathworks, Natick, MA), the Psychophysics toolbox (Brainard, 1997), and the Eyelink toolbox (Cornelissen, Peters, & Palmer, 2002). Gaze data was collected using the Eyelink 1000 remote eye-tracking system (SR Research, Osgoode, Canada). Corneal and pupil reflection were recorded at a sampling rate of 500 Hz. At the beginning of each block, a 9-point calibration was performed. Each trial began by requiring subjects to fixate on a central drift correction dot. After the eye-tracker registered a successful fixation, participants pressed the space bar to start the trial.

4.3.1.3 Procedure

Stimuli and apparatus were identical to those described in the Methods section of the Don't Look study in autism participants (see section 4.2.2.3 Procedure). They are described again here only for convenience.

Images were presented in three blocks, with 48 trials in each block. Images were shown individually in the center of the screen for five seconds each while eye-gaze was tracked. Experimental design consisted of three blocked conditions where viewing instructions were varied for each (see Figure 4.9-B for summary of experimental conditions). In one condition, viewing was unrestricted (Free View), and in the two remaining condition viewing was restricted (Avoid Eyes, Avoid Mouth). At the start of each block, subjects were instructed to examine the faces while following one of the following three viewing instructions: 1) avoid the

eyes ("Avoid Eyes" condition), 2) avoid the mouth ("Avoid Mouth"), or 3) view the images freely ("Free View"). Lastly, to insure the faces were being inspected in the "Avoid" conditions, subjects were told they might be asked to answer questions about the faces at the end of the experiment, though no actual post-experiment evaluation took place. Instruction order and image order were randomized.

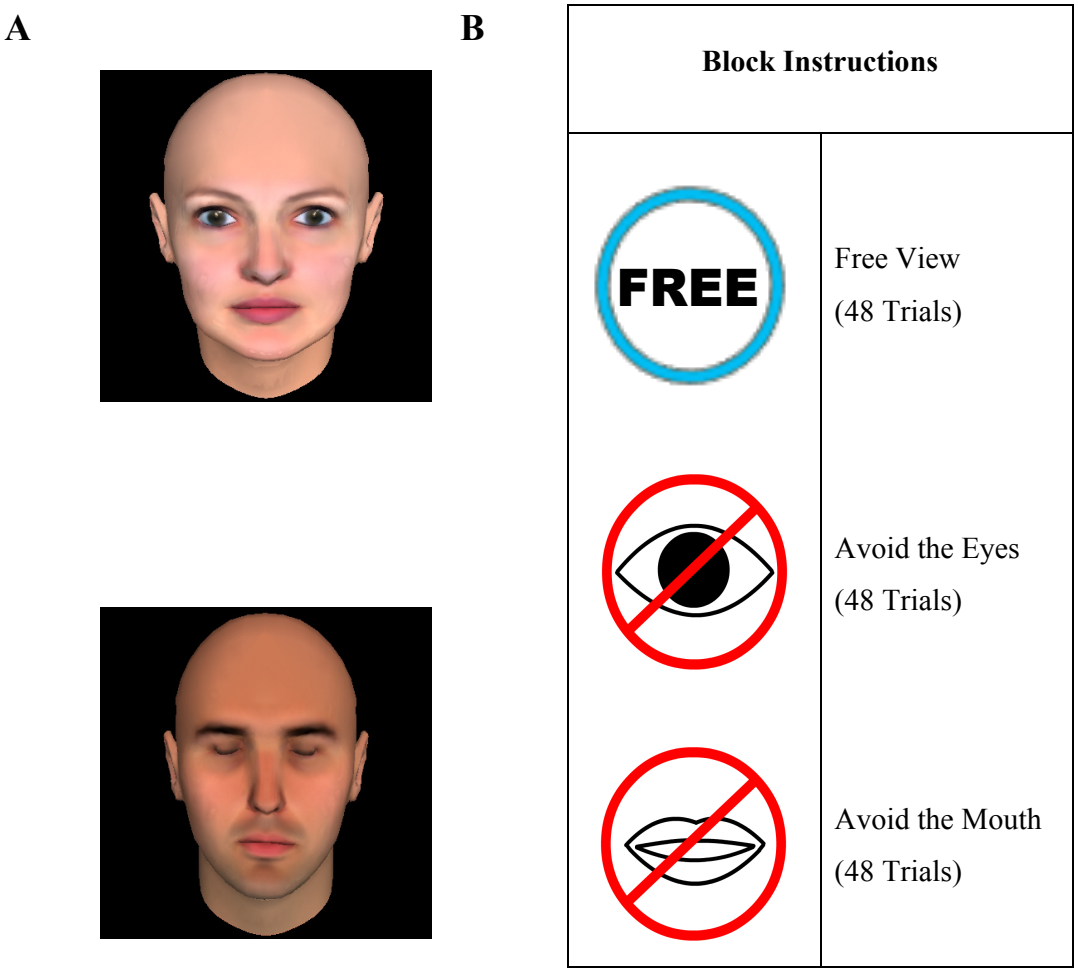


Figure 4.9. (A) Example stimuli showing Open Eyes (top) and Closed Eyes (bottom) faces, and (B) summary of experimental conditions.

4.3.1.4 Analyses

Analyses were identical to those described in the Methods section of the Don't Look study in autism participants (see section 4.2.2.4 Analyses). They are described again here for convenience.

Data were analyzed using custom scripts written in Matlab. Trials in which more than 20% of eye-tracking data was missing (due to blinks and/or signal loss) were excluded from analyses (< 3% of trials). Raw eye-tracking data was pre-processed to extract fixation locations and durations. Fixations were defined as gaze points falling within 1 degree of visual angle for a minimum of 100 milliseconds.

Because face stimuli differed in their locations of socially salient features, faces and the fixations on each face were normalized onto a template face using a morphing procedure (see section 4.2.2.2 Analyses and Figure 4.2). Each face was manually labeled with 94 anatomical landmark points (including eyes, mouth, nose, and head outline), and transposed using Delaunay Triangulation onto identical points marked on a prototypical template face. Fixation locations were subsequently morphed from their locations on the stimulus face to the equivalent locations on the template face. All subsequent analyses were performed on these normalized fixations on the template face.

To analyze gaze behavior, fixation heatmaps (or density maps) were calculated for each subject and condition by weighting fixation location by its duration, then spatially smoothing using a Gaussian kernel with sigma = 13, or 0.5 degrees of visual angle. Heatmaps were averaged across trials and subjects, and the resulting group maps were used for the ROI analyses described next.

We defined the following seven regions of interest (ROIs) on the template face: Left Eye, Right Eye, Eye Region Total, Nose, Mouth, Head Remainder, and Off-Head (see Figure 4.10 for a depiction of all regions on the template face). With the exception of Eye Region Total, which included Left Eye and Right Eye, ROIs were mutually exclusive. Designations for left and right eye are from the perspective of the viewer, not anatomical.

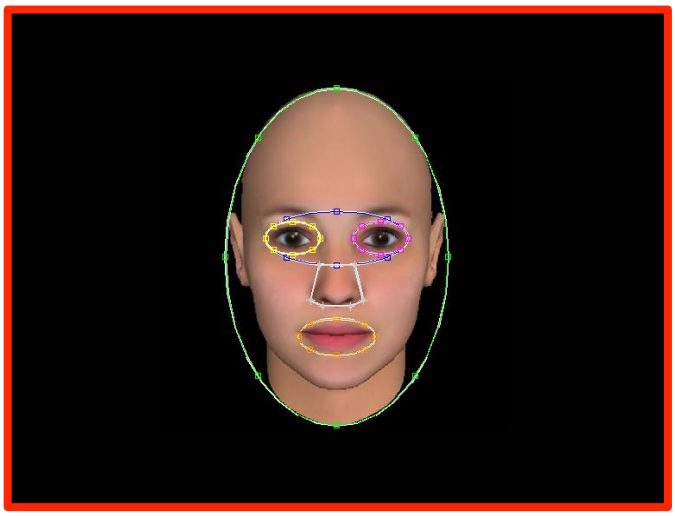


Figure 4.10. Template face with all regions of interest defined: yellow- left eye, magenta – right eye, blue – eye region total, gray – nose, orange – mouth, green – head remainder, red – off-head. With the exception of eye region total, which includes the left and right eyes, all regions were mutually exclusive.

We conducted three analyses examining 1) the proportion of gaze in all ROIs, 2) the distribution of gaze when it was in the eye region, and 3) center bias in the eye and mouth regions. Each analysis used a different subset of ROIs (see Figure 4.11).

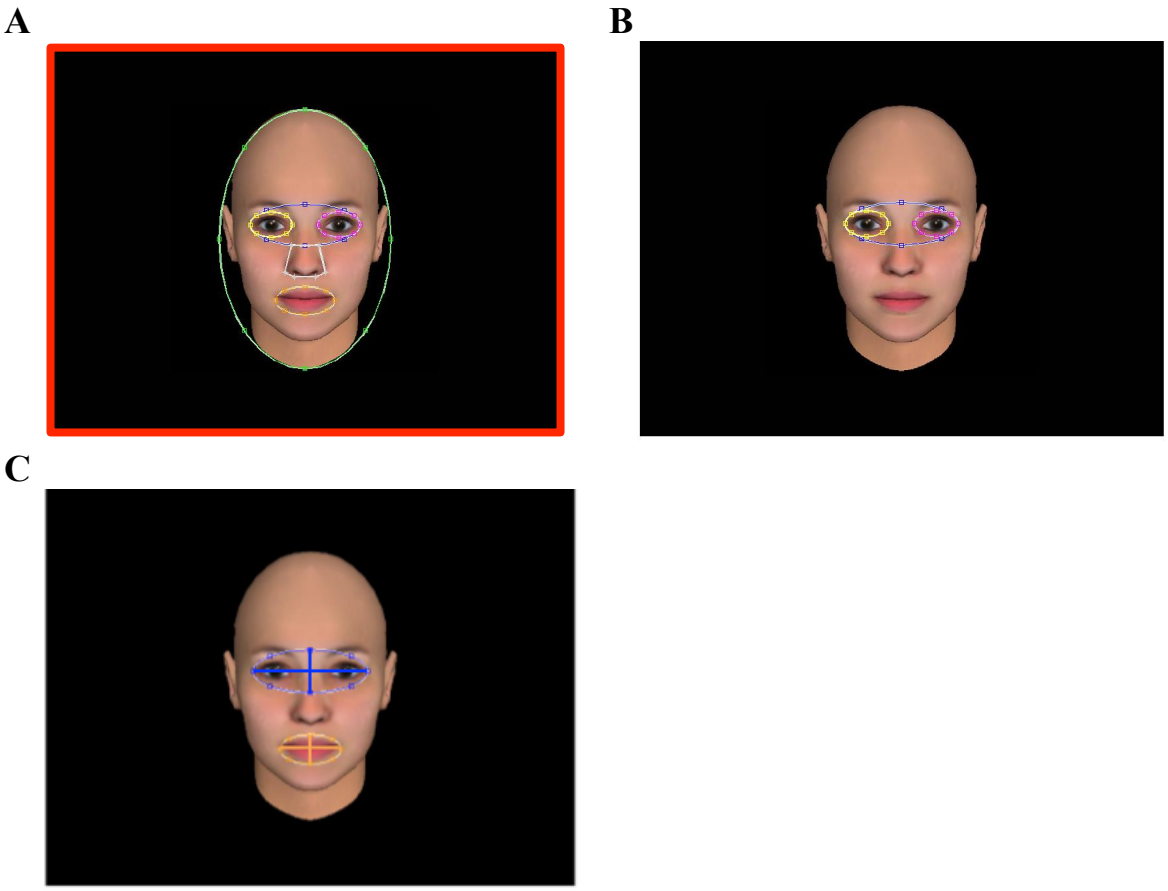


Figure 4.11. ROI configurations used in the different analyses. (A) Gaze proportions to all regions of interest, (B) Gaze proportion to the eye region, (C) Center Bias – average distance to the horizontal and vertical midlines.

For the first analysis examining gaze to all ROIs, we calculated the proportion of gaze time in each of the seven regions, summing the density map in each ROI and then dividing by the sum of the entire on-screen density map.

Given that total gaze to the eye region might be diminished in the amygdala group, we then conducted a second analysis comparing where gaze was distributed only in the eye-related ROIs (Left Eye, Right Eye, and the remainder of the Eye Region ellipse), calculating the proportion of time in each relative to total gaze in the eye region only (i.e., Eye Region Total)

rather than total gaze on-screen. This analysis would indicate whether the distribution of gaze among the three eye-related ROIs differed between groups.

Finally, for the analysis of center bias, we analyzed the two ROIs defining the socially salient regions of the face (Eye Region Total and Mouth). For the Eye and Mouth ROIs, we calculated the Euclidean distance for each point within the ROI to the vertical and horizontal midlines of the ROI, weighting each distance by gaze duration (i.e., the heatmap value for the point). Next, we summed these values, then divided by the sum of gaze in the ROI to obtain the average gaze distance to the horizontal and vertical midlines.

Statistical analyses were conducted by carrying out repeated-measures ANOVAs for each ROI in the analysis subset, with a between-subjects factor of group (amygdala, Control) and within-subjects factors of condition (Free View, Avoid Eyes, Avoid Mouth) and stimulus type (Open Eyes, Closed Eyes). In order to investigate the relationship of the two restricted conditions (Avoid Eyes, Avoid Mouth) against the unrestricted condition ("Free View"), appropriate contrasts were also conducted for gaze to the Right Eye, Left Eye, Eye Region Total, and Mouth.

4.3.2 Results

Heat maps for the amygdala subjects and control subjects in all three conditions are shown below in 4.12.

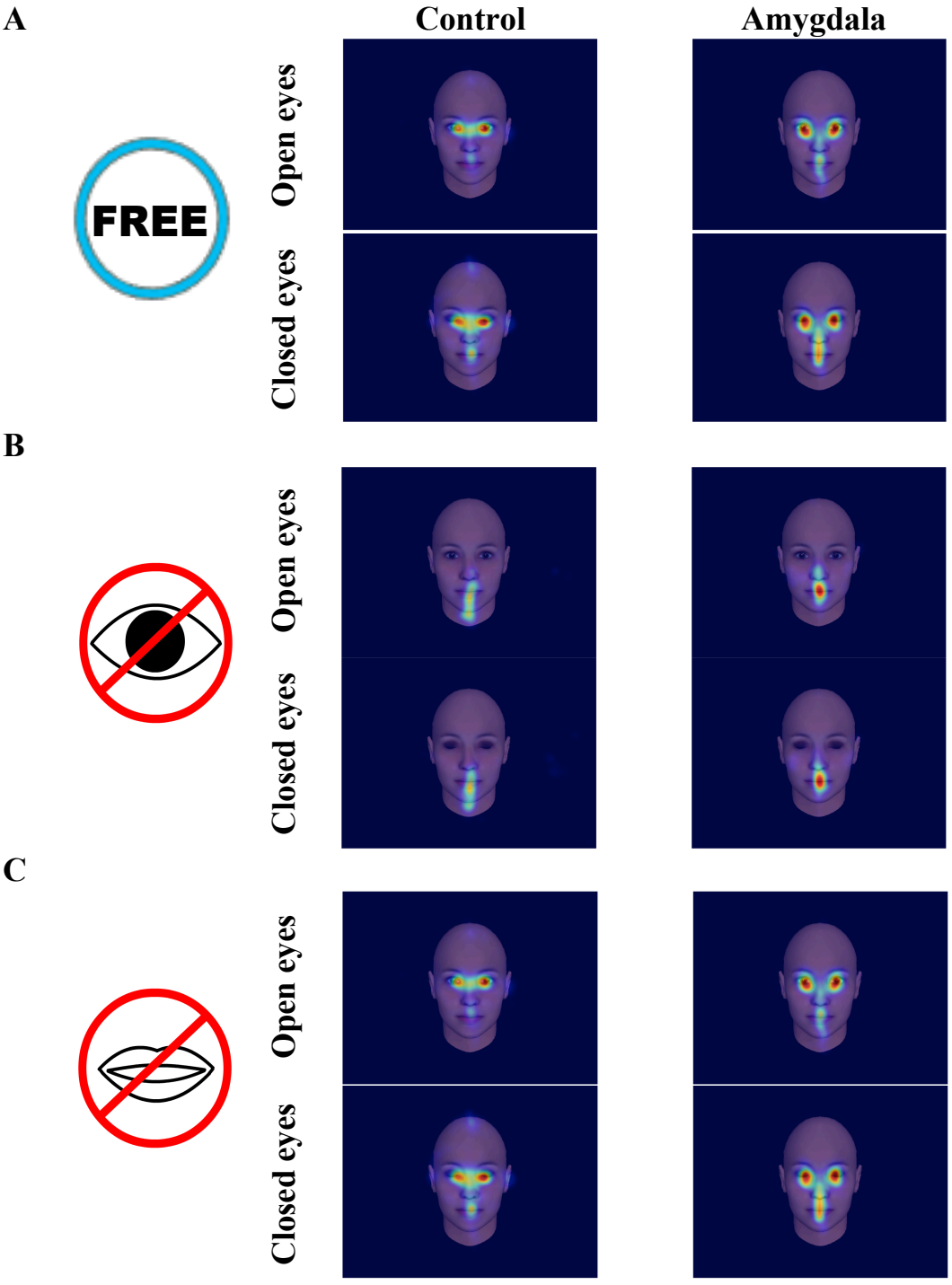

A
Control
Amygdala
Open eyes
Closed eyes
FREE
B
Open eyes
Closed eyes
C
Open eyes
Closed eyes

Figure 4.12. Heat maps for the amygdala and control groups, and conditions with Open Eyes and Closed Eyes stimuli. Maps were generated by using a Gaussian kernel function to spatially smooth each duration-weighted fixation point, then maps were averaged across trials and subjects. Warmer colors represent longer total fixation time.

4.3.2.1 Gaze Proportions in all regions of interest

The first set of analyses focused on gaze to the different regions of interest (see Figure 4.10-A for ROIs). A repeated-measures ANOVA with between-subjects factor of group and within-subjects factors of condition and stimulus was conducted for each of the seven ROIs (see Figure 4.13).

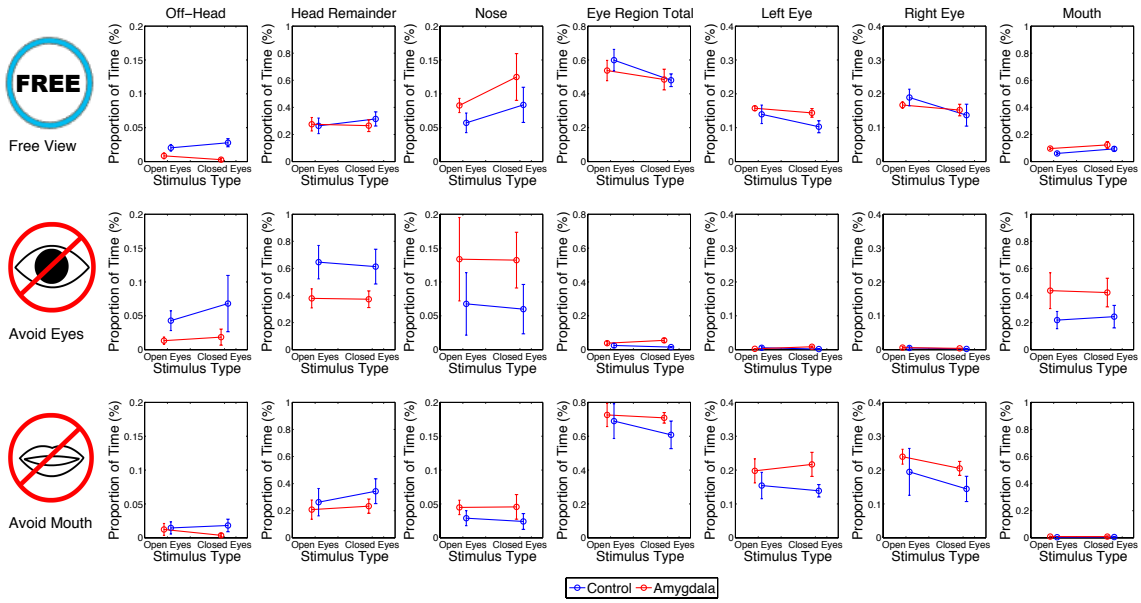


Figure 4.13. Proportion of fixation time in the ROIs in the amygdala (red) and control (blue) subjects. Error bars denote standard error.

Right Eye

The ANOVA for the right eye indicated there were no significant interactions involving group (all *p*s > .211), and no main effect of group (p = .578). Neither of the planned contrasts comparing the unrestricted condition to the two restricted conditions was significant (*p*s >

.216). There was, however, a main effect of stimulus type, $F(1,4) = 18.77$, $p = .012$, $\eta^2 = .892$, indicating that regardless of group, participants looked more at the right eye for Open Eyes stimuli than Closed Eyes stimuli (Open eyes: $M = 13.4\%$, $SD = 1.7$; Closed eyes: $M = 10.7\%$, $SD = 1.1$).

Left Eye

The ANOVA for the left eye indicated there were no significant interactions involving group (all *p*s > .225), and no main effect of group ($p = .148$). Neither of the planned contrasts comparing the unrestricted condition to the two restricted conditions was significant (*p*s > .218).

Eye Region Total

The ANOVA for the total eye region revealed no significant interactions involving group (all *p*s > .189), nor a main effect of group ($p = .228$). Neither of the planned contrasts was significant (*p*s > .375).

Mouth

The ANOVA for the mouth indicated there were no significant interactions involving group (all *p*s > .253), and no main effect of group ($p = .141$). Neither of the planned contrasts was significant (*p*s > .213).

Nose

The ANOVA for gaze to the nose revealed a marginally significant main effect of group, $F(1,4) = 4.40$, $p = .104$, $\eta^2 = .524$, suggesting greater gaze to the nose region in the amygdala group relative to controls (Amygdala: $M = 9.4\%$, $SD = 1.4$; Controls: $M = 5.4\%$, $SD = 1.4$). There were no significant interactions involving group (all *p*s > .691).

Head Remainder

The ANOVA for gaze to the head remainder revealed no significant interactions involving group (all *p*s > .200), nor a main effect of group ($p = .109$).

Off-Head

The ANOVA for gaze off-head revealed no significant interaction effects involving group (all *p*s > .145), but a marginally significant main effect of group, $F(1,4) = 4.38$, $p = .104$, $\eta^2 = .523$, suggesting there was less gaze to off the head regions in the amygdala group than in the control group (Amygdala: $M = 1.0\%$, $SD = 0.7$; Controls: $M = 3.2\%$, $SD = 0.7$).

4.3.2.2 Gaze distribution in eye region

To examine the distribution of gaze in the eye region, we calculated the proportion of gaze time in each eye ROI relative to the total gaze time spent in the entire eye region (see Figure 4.11-B for ROIs). Results are summarized below in Figure 4.14.

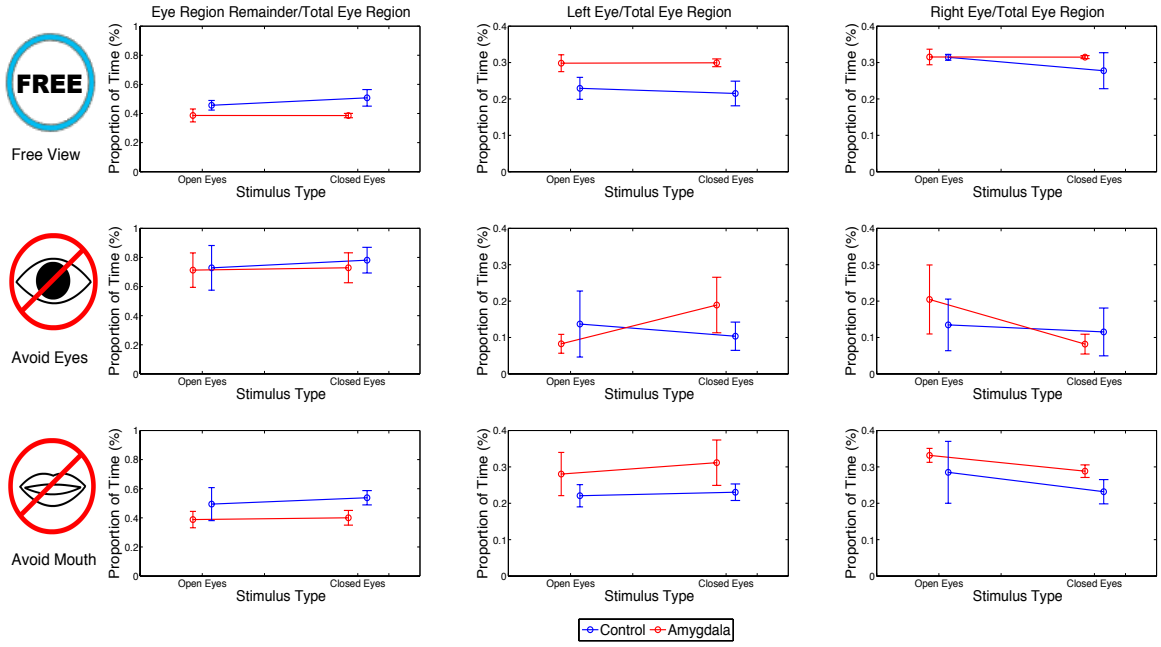


Figure 4.14. Gaze proportions in the eye region in the amygdala (red) and control (blue) groups. Error bars denote standard error.

Right Eye

The ANOVA for the right eye indicated there were no significant interactions involving group (all *p*s > .315), and no main effect of group ($p = .594$). Neither of the planned contrasts comparing the unrestricted condition to the two restricted conditions was significant (*p*s >

.390). There was, however, a significant main effect of stimulus type, $F(1,4) = 30.77$, $p = .005$, $\eta^2 = .980$, again indicating that regardless of group, participants spent a greater proportion of gaze in the eye region looking at the right eye for Open Eyes stimuli compared to Closed Eyes stimuli (Open eyes: $M = 26.4\%$, $SD = 2.8$; Closed eyes: $M = 21.8\%$, $SD = 2.3$). Neither of the planned contrasts was significant (ps > .390).

Left Eye

The ANOVA for the left eye revealed no significant interactions involving group (all ps > .124) and no main effect of group ($p = .448$).

Eye Region Remainder

The ANOVA for the remainder of the eye region revealed no significant interactions involving group (all ps > .255) and no main effect of group ($p = .354$). Neither of the planned contrasts was significant (ps > .710).

4.3.2.3 Center bias to horizontal and vertical midlines

To compare average gaze distance (measured in degrees of visual angle) from the vertical and horizontal midlines in the socially salient regions of the face, a two repeated-measures ANOVAs for the Eye Region and Mouth ROIs was conducted (see Figure 3.3-C for ROIs).

Eye Region

The ANOVA for the eye region indicated there were no interactions involving group (all ps >.557) and no main effect of group ($p = .403$) for distance to the vertical midline. There were also no interactions involving group for distance to the horizontal midline (all ps >.157), and no main effect of group for distance to the horizontal midline ($p = .581$).

Mouth

The ANOVA for the mouth did not reveal any significant interactions involving group for distance to the vertical midline (all ps > .291), nor a main effect of group ($p = .799$). There were also no significant interactions involving group for distance to the horizontal midline (all ps > .737), nor a main effect of group ($p = .970$).

4.3.3 Discussion

We tested three patients with rare amygdala lesions to examine whether social processing impairments would affect spontaneous face gaze strategies, and also the flexibility of those strategies in response to changing viewing contexts. Similar to the limitations of the gaze cascade study in amygdala lesion subjects, group comparisons lacked the statistical power to allow us to draw quantitative conclusions due to the small sample size. Overall, the amygdala lesion patients exhibited a similar general pattern of face gaze, preferring to explore the face rather than off-face regions of the screen, and in similar proportions as controls. However, there were a few notable effects as well as some qualitative trends in the data that seem worthy of discussion.

In the unrestricted condition, amygdala group exhibits a similar pattern of face gaze as controls, spending the majority of gaze time looking at the eye region the most, followed by the remainder of the face. The amygdala patients also spent the same proportion of fixation time looking at the mouth as the nose, which was similar to the pattern observed in controls. This indicates that gaze to the core features in the absence of an explicit decision-making task is intact in amygdala lesion subjects. Both groups also performed equally well in avoiding the eyes and mouth in the "Avoid Eyes" and "Avoid Mouth" conditions, respectively. Similar to the controls' gaze behavior, when the eyes were to be avoided, the amygdala group increased gaze to the mouth, and when the mouth was to be avoided, the amygdala group increased gaze to the eyes, indicating that the amygdala group likely recognizes the saliency of these two regions.

There was a main effect of stimulus type for gaze to the right eye, indicating that regardless of group, participants looked more at the right eye with Open Eyes stimuli compared to Closed Eyes stimuli. This result is interesting given our previous finding for a right eye bias in controls, as well as reports in the literature of greater expressivity conveyed by the left hemiface (Borod, Haywood, & Koff, 1997; Powell & Schirillo, 2009; Sackeim, Gur, & Saucy, 1978). That the right eye bias is intact in the amygdala group suggests that they are sensitive to the quality of information that is conveyed by the different sides of the face.

In the Avoid Eyes condition, there is an interesting parallel to our findings in the autism group, in that both the amygdala group and control group increased gaze to the mouth compared to their behavior in the unrestricted condition, but the magnitude of increase in the amygdala group was much higher than the control group. We found a similar effect in the autism subjects, who showed a disproportionally large increase in gaze to the mouth in the Avoid Eyes condition, while controls also distributed their gaze to exploring the remainder of the face. This could indicate a similarly diminished propensity for flexible face exploration in the two clinical groups.

There was an additional parallel to the autism group in gaze to the nose region, such that there was an overall trend for greater nose gaze in the amygdala subjects compared to control subjects. We observed this trend across all three conditions in the amygdala group. The autism group showed a comparable bias toward the nose region, though it was limited to the unrestricted condition.

In the Avoid Mouth condition, amygdala patients, as well as control subjects, returned to the gaze behavior they demonstrated in the unrestricted condition for the majority of ROIs, but there were differences in two regions that merit future study. First, gaze to the remainder of the face decreased in Avoid Eyes compared to Free View for the amygdala group, but remained the same in the control group, which suggests again that there may be a reduced tendency to explore the face. Second, the increase in gaze to the eye region compared to "Free View" was also larger in the amygdala group than in controls, indicating a bias for fixating the salient regions more than controls in the restricted conditions.

Finally, though the difference between groups for gaze off the head did not reach significance, the findings suggest that the amygdala group spent less time off the head than controls regardless of condition, preferring instead to continue looking at the face. Combined with the larger bias for fixating socially salient ROIs in the restricted conditions, one question to be explored in future studies is whether people with amygdala lesions experience the same level of negative arousal or discomfort from looking at salient face features. There is already evidence to show that the amygdala contributes to one's sense of personal space (Kennedy, Gläscher,

Tyszka, & Adolphs, 2009), such that people with amygdala lesions show less discomfort from standing in close proximity to strangers. It would be interesting to explore if the sense of smaller personal space also extends to abnormally intense face gaze, especially to the eye region.

An additional question for exploration is whether the amygdala group demonstrates *less* of a center bias than controls. The heatmaps suggest that amygdala subjects were more intensely focused on the pupils of the eyes compared to controls, and also explored the region between the eyes less than controls. A similar effect is evident in gaze to the mouth region, such that fixations in the amygdala group were tightly focused in a smaller region centered on the mouth when compared to controls' fixations.

The lack of systematic group differences in gaze to the ROIs suggests that the amygdala is not relied upon for basic perceptual processing of faces. The findings are consistent with studies pointing to a greater role of the amygdala in emotional processing of faces rather than general face processing, which relies more on the fusiform gyrus and superior temporal sulcus (Haxby et al., 2002).

Similar to the gaze cascade study in amygdala lesion patients, the absence of significant effects in our study may also have been due to small sample sizes. Thus, while our findings suggest that the amygdala does not play a critical role in basic perceptual processing of faces, future studies using larger sample sizes will be necessary to elucidate if this conclusion holds true.

4.4 Conclusion

In this chapter I explored face gaze strategies and the flexibility of those strategies in changing viewing contexts in autism and patients with amygdala lesions. I used an implicit behavioral task that investigated how flexible and automatic face processing is and how well it can be cognitively influenced outside of the context of preference decision-making.

I found there was a general tendency to look at the eye region in the absence of an explicit task in both ASD and amygdala lesion patients. While details of gaze to the eye region in the amygdala group were no different from controls, the ASD group showed several notable differences. Consistent with evidence of abnormal gaze lateralization, people with ASD were less efficient than neurotypicals in distributing gaze to the eye region, demonstrating a center bias for the region between the eyes and a lack of gaze lateralization to the right eye. I also found that people with ASD demonstrate less flexible viewing behavior due to either a diminished interest or a diminished ability to continue exploring the face in the restricted conditions. It is interesting to note that in the people with ASD, part of the atypical compensatory strategy they used consisted of a rather strong center bias to the region between the eyes. This is quite different from the face scanning strategy observed in the amygdala lesion patients, who appear to show *less* of a center bias toward the eye region compared to controls, and indeed seem to fixate on the pupils of the eyes more than controls. A similar intensity of fixation was also observed in the amygdala subjects when looking at the mouth region.

The amygdala group demonstrated a similar right eye bias as controls and appeared equally flexible in gaze strategies. There was, however, a tendency in the amygdala group to look away from the salient parts of the face less often than controls, and also to look off the head less than controls, which is consistent with evidence showing reduced discomfort during violations of personal space.

The results from these studies suggest that face scanning utilizes general perceptual process that might not be reliant upon amygdala functioning. Moreover, the results suggest that the reduced flexibility of face gaze strategies observed in people with autism is not primarily based on amygdala dysfunction. One possibility to be explored is that the reduced flexibility of face

gaze strategies in ASD may be linked to structural and functional abnormalities that have been reported in the superior temporal sulcus (Zilbovicius et al., 2006) and the fusiform gyrus (Hubl et al., 2003; Schultz et al., 2000).

C h a p t e r V

GENERAL DISCUSSION AND FUTURE DIRECTIONS

5.1 Summary

In this dissertation, I investigated social gaze and face preferences in people with autism and amygdala lesions. In Chapter III, I examined visual behavior and face preference formation, exploring how social processing deficits affect gaze behavior and subjective decision-making for faces. In chapter IV, I explored how flexible and automatic face processing strategies were and how well they can be cognitively influenced outside of the context of explicit decision-making.

I found that people with autism and amygdala lesion patients made similar preference decisions as controls in judging face attractiveness, and that both groups also demonstrated similar preference *biases* as controls. In addition, people with autism demonstrated a similar visual sampling process linking preference and attentional orienting. My findings provide evidence for the idea that face preference formation can be preserved, or compensated for, in the presence of general social processing impairments.

The findings also indicate that face preference formation appears to circumvent face processing deficits reported in other studies of higher-order social decision-making, possibly through compensation by processing and attentional strategies. There were two key differences in the autism group that pointed to the use of atypical social processing strategies. First, with respect to reaction times, people with autism made preference decisions for faces faster than the controls, and their reaction times also appeared insensitive to the difficulty of the choice when deciding amongst faces. Based on the absence of a reaction time advantage in comparison tasks involving objective decisions or non-social stimuli, this suggests that there is a higher-level component of preferential decision-making for faces that is altered in people with autism while the preference formation mechanism linking gaze orienting and eventual choice remains intact. The reaction time advantage observed in ASD with respect to face preference decisions

suggests specific hypotheses that should be investigated in further, more refined studies, and may point to an advantage that arises specifically during face preference formation.

Second, I found that in the absence of an explicit decision-making task, people with autism demonstrated abnormalities in face gaze patterns, looking less at the parts of the eye region that communicate the most information. People with autism also demonstrated rigidity in gaze behavior that adhered to imposed viewing restrictions but at the cost of extensive exploration of the face, showing people with autism have difficulty updating pre-existing face scanning strategies in changing social contexts. Therefore, while deficits in social processing do not appear to significantly impair the preference formation process for faces, there is also evidence showing that people with autism use atypical processing and visual strategies when looking at faces, perhaps in part to compensate for these deficits. More detailed analysis of task difficulty, reaction times, and even face preferences would help here, and in the future, to determine whether subjective decisions about faces systematically differ in people with ASD.

What are the broader implications that can be drawn from these results? First, an implicit and subjective approach to investigating social processing is a valuable tool for characterizing social impairments in ASD. Indeed, the term "social processing" may be too large of an umbrella term to apply to the deficits observed in ASD, and there may be an array of unstudied implicit and subjective components that are unimpaired. Because autism is so heterogeneous, it will be important to investigate specific aspects of social processing to understand if they are actually impaired. Second, nuanced differences at the surface could belie larger differences in underlying mechanism. There may be small differences in behavior in practiced conditions but these behaviors could reveal a lack of ability to adapt to new constraints. Therefore, in addition to measuring various aspects of social behavior, we need to also characterize how these behaviors are adapted when they must be updated. Third, information-seeking strategies in ASD can be better characterized by including behavioral responsiveness and resilience. Real-life situations demand continual adjustment and responsiveness to new situations. To fully understand social deficits in ASD, we cannot simply measure the baseline behavior, but must also test responsiveness and resilience to better characterize and treat social impairments.

In conclusion, an implicit and subjective approach yields important insight into social processing in ASD. By using this approach, in people with specific deficits, we learn not only about what causes known social impairments but we also learn more about what constitutes normal social functioning, with the hope that we can better characterize the difficulties experienced in ASD.

5.2 Limitations

It is important to acknowledge the limitations of these studies. First, the autism participants consisted of individuals who were high-functioning. We cannot rule out the possibility that the findings reported here apply to a very specific sub-type of high-functioning individuals who are on the rather social end of the spectrum given their willingness to interact with researchers and participate in hours of experiments. Consequently, it remains an open question whether the findings reported here would also extend to low-functioning individuals who show greater impairment, and often have comorbid developmental disorders that impact social and executive functioning. Moreover, there is a further caveat with regard to the population demographics, in that males were heavily over-represented in the autism group, which partially reflects a problem with underdiagnosis of autism in women. Recent research shows that there are gender differences in the symptoms of autism (Head 2014, Frazier 2014), with females more likely to demonstrate social impairments but not the restricted interests and repetitive behaviors that are characteristic of autism, which leaves open the question of whether females with autism would demonstrate the same patterns social preference and gaze behavior.

There is also a limitation with respect to the experiment stimuli that were used. As is often the case in experimental design, there is a tradeoff between ecological validity and experimental control. While the use of computer-generated faces is favorable in terms of controlling for potential confounds such as lighting and facial expression, making preference decisions for computer-generated stimuli might not be the same as making attractiveness judgments for real faces. Social stimuli with greater ecological validity (such as photographs or dynamic stimuli) may be more likely to elicit atypical gaze behavior, particularly in individuals with high-functioning autism and the use of such stimuli should be considered for future studies.

5.3 Future Directions

Based on the evidence that processing of social information and the appearance of social impairments can vary widely in people with autism based on explicit task demands, it will be important for future autism studies to examine implicit social processing. Especially, it may be worth paying attention to the initial phase of orienting and perceptual processing leading up to the preference decisions. In future work, researchers might focus efforts on investigating initial orienting to social stimuli and the perceptual processes involved in social processing by decoupling measurements of behavior from an explicit decision-making task.

Another important piece of the autism research puzzle is improving our understanding of the brain behavior link. There is a need to trace higher-level behavioral outcomes to the implicit and explicit processing mechanisms underlying them. For this reason, concomitant neuroimaging or EEG during preference decision-making tasks would be highly informative to our understanding of how social deficits affect face processing in ASD. Given that so much of our response to faces occurs automatically and sub-consciously, current decision-making paradigms are limited in that they largely measure the conscious realization of an explicit judgment, rather than the subconscious evaluative processes upon which the decision is predicated. As a consequence, we might be in fact measuring the ability of people with autism to compensate for outcomes despite an underlying impairment, rather than measuring the actual deficit as it exists and is experienced by people with autism. Mapping the brain mechanisms preceding or taking place during these social processing tasks can strengthen our understanding of how social processing deficits are directly linked to attentional and behavioral strategies, as well as the outcome of those strategies.

Future studies of explicit decision-making tasks might also use more trials so that comparisons can be made between trials in which preferences were either congruent or incongruent with the preferences of controls, and to examine whether there are differences in gaze behavior in trials that were congruent versus incrongruent. Neuroimaging or EEG would also be advantageous here in that brain activity can be compared between congruent and incongruent trials, to explore whether there is an interaction between processing mechanisms, gaze behavior, and decision outcomes.

Studies using dynamic face stimuli and more complex social stimuli will be important in understanding the specific contexts in which social impairments occur in high-functioning autism. It could be the case that face processing deficits in high-functioning ASD become evident only when there are more complex attentional demands, such as in real-life situations, or when there is competing visual information, such as with dynamic stimuli. This could also occur if attentional demands become too great to sustain explicit or implicit compensatory strategies. In future work, researchers might investigate the extent to which deficits in processing social information affect preference decisions using dynamic or emotional stimuli.

Symptoms, behaviors and even the underlying genetic causes of ASD are widely heterogeneous, which poses a significant challenge to researchers and clinicians alike. On a more global level, an important future task for research and diagnosis will be to improve characterization of the autism phenotype. Differences in social processing, face processing, decision-making are distributed across a wide range in the general population. Research has shown this variability extends to ASD, with some people with autism showing no differences from the general population in certain tasks and others showing severe impairments. Based on this evidence, a major question to consider is to what extent do the differences in people with autism overlap with differences observed in general population? Moreover, to what degree do these differences in autism really constitute a behaviorally and biologically distinct group versus simply being clustered at one extreme of an otherwise normal distribution?

The considerable heterogeneity in phenotypic presentation also underscores one of many gaps in our understanding of ASD regarding the differences that distinguish subtypes of ASD. There is significant variability in the cognitive and behavioral profiles of individuals who meet diagnostic criteria for ASD and there is a need to identify and characterize meaningful sub-types of ASD that map onto patterns of impairments (and the degree of those impairments) in a way that current diagnostic and research criteria fail to capture.

To better diagnose each individual under the broader spectrum and develop new treatment approaches, future research needs to include tasks that would help identify these sub-types at a diagnostic level and characterize the specific social deficits experienced by the individual.

Consequently, it will be important in the next stage of autism research to move beyond group-level investigations, to examining within-group differences amongst sub-types of ASD, as well as drawing connections to what these sub-types mean for development and outcomes for the individual.

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